

SOLAR THERMAL TECHNOLOGY REPORT

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PREPARED BY:

Enermodal Engineering Limited
368 Phillip Street, Unit 2
Waterloo, Ontario N2L 5J1
(519) 884-6421

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Energy, Mines and
Resources Canada

Hon. Marcel Masse,
Minister

Énergie, Mines et
Ressources Canada

L'Hon. Marcel Masse,
Ministre



Ministry Robert C Wong
of Minister
Energy

Ministère Robert C Wong
de
L'Énergie

EXECUTIVE SUMMARY

This report summarizes the status of active solar thermal technology in Ontario and the rest of Canada.

Annual Canadian sales of solar equipment have levelled off at about 99000 square metres and 14 million dollars, with 40% of the market being in Ontario. There are three main markets for solar equipment: seasonal pool heating, residential water heating, and commercial/industrial process water and air heating. The market for space heating is virtually non-existent. Solar DHW systems have the largest market share at 50%; pool (25%), commercial/industrial-liquid (22%) and commercial/industrial-air (3%) make up the rest of the market.

The sale of swimming pool collectors is a mature and well-established market. Solar swimming pool systems are reliable, and are being installed without government subsidy. The success of one Ontario manufacturer has led to approximately 40% of the Canadian production being exported to the U.S.

The cost of solar domestic hot water systems has fallen by 60% since 1981 due to the development of lower cost and more easily installed systems. System reliability has improved dramatically, although controller and pump failures remain a minor problem. System performance is often low (1.3 GJ/m^2 per year), because the system is oversized relative to the load (a properly sized system should deliver 1.8 to 2.0 GJ/m^2 annually). Solar DHW system cost performance needs to be reduced by 50% in order for these systems to compete in the Ontario market place without government subsidy.

The performance and reliability of solar Commercial/Industrial/Institutional systems has improved significantly over the last few years. Properly designed and operated systems could deliver 2.4 GJ/m^2 annually. The control system is the system component with the lowest reliability. The current cost effectiveness of C/I/I systems is more than three times the 1981 value. Most of the systems, however, are still three to four times too expensive to penetrate the Ontario market without subsidies. Exceptions could possibly include ventilation air preheating and heating of fish hatchery water.

The Canadian solar industry is well served by support services: the National Solar Test Facility provides testing services for collectors and solar DHW systems; the WATSUN Simulation Laboratory provides access and support for computer simulation programs for most solar heating system types; the Canadian Standards Association has standards for collectors and solar DHW systems; and the University of Waterloo, Queen's University, and INRS are conducting research on solar heating systems.

When government subsidy programs end in 1988, the solar industry will face a difficult task in maintaining market share; there are, however, several niche market and regions of Canada where solar heating may have market penetration. Cost reductions and performance improvements are possible, through further refinement of the micro-flow solar DHW system and mega-collectors: these advancements should increase the salability of solar heating systems.

SOMMAIRE

Voici un compte rendu de l'état d'avancement des techniques d'exploitation active de l'énergie solaire en Ontario et dans le reste du Canada.

Les ventes annuelles de matériel solaire au Canada se sont stabilisées à 14 millions de dollars, soit environ 99 000 mètres carrés de capteurs, dont 40 pour 100 sont écoulés en Ontario. Il existe trois marchés principaux pour le matériel solaire : le chauffage saisonnier des piscines, le chauffage de l'eau domestique et le chauffage de l'eau et de l'air dans les commerces et les industries. Le marché du chauffage des locaux est presque inexistant. Ce sont les chauffe-eau solaires domestiques qui se taillent la part du lion (50 %), suivis des systèmes de chauffage des piscines (25 %), puis des systèmes de chauffage des liquides (22 %) et de l'air (3 %) dans les commerces et les industries.

Le marché des capteurs pour piscine est bien établi. Les systèmes solaires pour piscine sont fiables, et ils sont installés sans subvention du gouvernement. Grâce au succès d'un fabricant ontarien, environ 40 pour 100 de la production canadienne est exportée aux États-Unis.

Le coût des chauffe-eau solaires domestiques a baissé de 60 pour 100 depuis 1981. Leur fiabilité s'est beaucoup améliorée, même si les pannes de régulateur et de pompe continuent à causer de petits problèmes. Le rendement est souvent faible en raison de la grande taille des chauffe-eau par rapport à la charge (un chauffe-eau bien dimensionné devrait produire de 1,8 à 2,0 GJ/m² par an). Le rapport coût-rendement des systèmes de chauffe-eau domestiques doit être réduit d'environ 50 pour 100 pour qu'ils soient concurrentiels sur le marché ontarien, sans subvention du gouvernement.

Le rendement et la fiabilité des systèmes utilisés dans les commerces, les industries et établissements divers se sont beaucoup améliorés au cours des quelques dernières années. Des systèmes bien conçus et bien exploités pourraient produire $2,4 \text{ GJ/m}^2$ par an. Le système de régulation est la composante la moins fiable. Le rapport coût-rendement est trois fois meilleur qu'en 1981, mais la plupart des systèmes restent de trois à quatre fois trop chers pour percer le marché ontarien sans subvention. Les systèmes destinés au préchauffage de l'air de ventilation et au chauffage de l'eau pour les écloseries de poissons constituent peut-être des exceptions.

L'industrie solaire canadienne est bien appuyée : le Centre national d'essai d'équipements solaires permet de faire l'essai des capteurs et des chauffe-eau solaires domestiques; le laboratoire de simulation WATSUN offre des programmes de simulation et des conseils pour la plupart des types de systèmes de chauffage solaires; l'Association canadienne de normalisation établit des normes pour les capteurs et les chauffe-eau solaires domestiques; et l'Université de Waterloo, l'Université Queen et l'Institut national de recherche scientifique mènent des recherches sur les systèmes de chauffage solaires.

Lorsque les programmes de subvention du gouvernement prendront fin en 1988, l'industrie solaire sera confrontée à la tâche difficile de maintenir sa part du marché. Il existe toutefois plusieurs créneaux et, dans certaines régions du Canada, le chauffage solaire pourrait percer. Il est possible de réduire les coûts et d'améliorer les rendements en perfectionnant les méga-capteurs et la technique du micro-débit appliquée aux chauffe-eau solaires domestiques. Ces perfectionnements devraient augmenter l'attrait du matériel solaire.

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TABLE OF CONTENTS

	<u>Page</u>
EXECUTIVE SUMMARY	i
ACKNOWLEDGEMENTS	iii
DISCLAIMER	iv
TABLE OF CONTENTS	v
LIST OF FIGURES	vii
LIST OF TABLES	viii
1. INTRODUCTION	1
1.1 Background	1
2. SOLAR HEATING SYSTEM COMPONENTS	5
2.1 Solar Collectors	5
2.1.1 Swimming Pool Solar Collectors	5
2.1.2 Flat Plate Collectors	8
2.1.3 Evacuated Tube Solar Collector	17
2.1.4 Concentrating Solar Collectors	20
2.1.5 Solar Collector Heat Transfer Fluids	20
2.1.6 Characterizing Collector Thermal Performance	22
2.2 Collector Support Systems	27
2.3 Thermal Heat Storage	28
2.3.1 The Importance of Thermal Heat Storage	28
2.3.2 Thermal Storage for Liquid-based Systems	28
2.3.3 Thermal Storage for Air-based Systems	29
2.4 Heat Exchangers	32
2.5 Control Systems	32
3. SOLAR HEATING SYSTEMS	33
3.1 Seasonal Solar Pool Heating Systems	33
3.1.1 System Descriptions	33
3.1.2 Performance and Reliability	36
3.1.3 Economics and Market	36
3.2 Solar Domestic Hot Water Systems	37
3.2.1 System Description	37
3.2.2 Performance and Reliability	51
3.2.3 Economics and Market	53
3.3 Active Solar Space Heating Systems	55
3.3.1 System Description	55
3.3.2 Performance and Reliability	63
3.3.3 Economics and Market	63
3.4 Commercial/Industrial/Institutional Solar Heating Systems	63
3.4.1 System Descriptions	63
3.4.2 Performance and Reliability	67
3.4.3 Economics and Market	74

4.	ASSESSMENT OF ACTIVE SOLAR INDUSTRY	78
4.1	Canadian Solar Manufacturers and Their Products	78
4.2	Solar Technology Outside of Canada	79
4.3	Research and Support Facilities	80
4.4	Codes and Standards	85
4.5	Performance Prediction Tools	87
4.6	Design and Installation Manuals	91
5.	FUTURE TRENDS IN SOLAR THERMAL TECHNOLOGY	93
5.1	Equipment and Systems	93
5.2	Economics	94
6.	CONCLUSIONS	97
7.	REFERENCES	98

LIST OF FIGURES

	<u>Page</u>
1.1 Canadian Collector Sales	3
1.2 Canadian Solar Market Share by System Type	4
2.1 Typical Swimming Pool Solar Collector	7
2.2 Typical Liquid-Based Flat-Plate Collector	9
2.3 Typical Air-Based Flat-Plate Collector	10
2.4 Internal and External Manifolds	13
2.5 Thermal Diode Type Collector	15
2.6 Production Cost Breakdown for a Typical Flat-Plate Collector	16
2.7 A Large Site-Assembled Collector for Industrial Applications	18
2.8 Typical Evacuated Tube Collector	19
2.9 Concentrating Solar Collectors	21
2.10 Collector Efficiency Curve	24
2.11 Typical Rock Bed Thermal Storage Unit	30
3.1 Typical Swimming Pool Solar Heating System Schematic	34
3.2 Largest Solar Pool Heating System in Canada	35
3.3 Typical Drainback Solar DHW System Schematic	38
3.4 Micro-flow Solar DHW System Schematic and Piping	41
3.5 Typical Antifreeze Solar DHW System Schematic	42
3.6 Typical Thermosyphon Solar DHW System	45
3.7 Batch Solar DHW System	47
3.8 Typical Recirculation Solar DHW System	48
3.9 Typical Antifreeze Thermosyphon System	49
3.10 Average Installed Cost of Solar DHW Systems in 1987 Dollars	54
3.11 The Cost Performance of Solar DHW Systems	56
3.12 Solar DHW Cost Breakdown	57
3.13 Typical Liquid-Based Solar Space Heating System Schematic	59
3.14 Typical Air-Based Solar Space Heating System Schematic	61
3.15 Largest C/I Solar Water Heating System in Ontario	65
3.16 Typical Solar Preheated Ventilation Air System	66
3.17 Cost Breakdown of a Typical C/I Solar Heating System	75
3.18 Cost Performance Com/Ind Solar Systems	76
4.1 Solar Simulator Used at the NSTF	81
5.1 Variable-volume Solar Heating System Schematic	95

LIST OF TABLES

	<u>Page</u>
2.1 Operating Temperatures for Solar Collectors	6
3.1 Performance of Liquid-Based Solar Systems Installed under the Ontario C/I Solar Demonstration Program	68
3.2 Performance of Air-Based Solar Systems Installed under the Ontario C/I Solar Demonstration Program	71
3.3 Performance of Monitored Solar Systems under the EMR C/I Demonstration Program	73
3.4 Ranking of Components from Least to Most Reliable	74
4.1 Ontario Sites for Which Solar Radiation Values Are Available	90

1. INTRODUCTION

This report summarizes the status of active solar thermal technology in terms of available products and systems, support services, economics, performance and future prospects. The report emphasis is on solar technology found in Ontario and, to a lesser extent the rest of Canada. Solar technology outside of Canada is discussed only if it might reasonably be applied in Ontario. This report is restricted to active thermal solar and does not examine other solar technology such as passive solar or photovoltaics.

1.1 Background

In Ontario active solar technology began in the mid-1970's with a few small companies producing solar collectors mostly for residential space heating. The growth of the industry was stimulated by the federal and provincial governments. In 1978 the federal government announced two solar industry support programs with funding up to \$125 million: PASEM and PUSH. PASEM (Program for Assistance to Solar Energy Manufacturers) gave 10 Canadian companies (seven of which were in Ontario) financial assistance to improve product designs and manufacturing capabilities. PUSH (Purchase and Use of Solar Heating) allocated funds for the purchase of solar heating systems for federal government buildings. The National Research Council managed a solar R and D program with an annual budget of approximately \$10 million. In 1983 these programs were replaced with a \$79 million program of research, development and demonstration in order to make the industry self-supporting in five years. In 1984 the Division of the National Research Council was phased out and R and D responsibilities were transferred to Energy, Mines and Resources Canada. The current solar demonstration program is scheduled to end in March 1988.

The Ontario government, through the Ministry of Energy, has also provided support for the active solar industry. Between 1981 and 1984, the Ministry provided partial financial support for the installation of solar heating systems on commercial/industrial non-profit, municipal, religious and government buildings. The Ontario program, with a budget of \$13 million, resulted in almost 200 solar installations.

Government support has excluded residential seasonal swimming pool systems, which provide heat only during one or two seasons (usually the summer). This technology was seen as well-developed and cost-effective. Recently, the EMR program was modified to include seasonal pool systems for commercial/institutional applications.

The sales of solar collectors reflect the government support programs (see Figure 1.1). Sales grew rapidly in the late 70's and early 80's, but have more or less levelled off since 1981. The current Canadian volume of business is 99000 square metres or about \$14 million annually [1]. The dollar value is the total installed cost for Canadian systems plus the wholesale cost of export systems. Solar swimming pool systems represent the majority of sales on an area basis, but their low cost and high export content (approximately 40%) result in a market share on a dollar basis of only about 25% (see Figure 1.2). Domestic hot water solar systems represent the largest market, at just over 50%. Air systems, at about 3%, represent a very small portion of the market. Use of solar collectors for residential space heating is essentially non-existent.

Product sales have very definite regional trends. The major Canadian market for swimming pool collectors is Ontario (50%) because of the large number of swimming pools. The Ontario market share drops to 30% and 34% for the commercial/industrial and domestic hot water markets respectively [2]. The largest market for commercial/industrial systems is Atlantic Canada (43%) due, in most part, to aggressive marketing by a regional manufacturer and high local energy costs. Quebec is a major market for solar domestic hot water systems (27%), again due to aggressive marketing by a Quebec-based manufacturer.

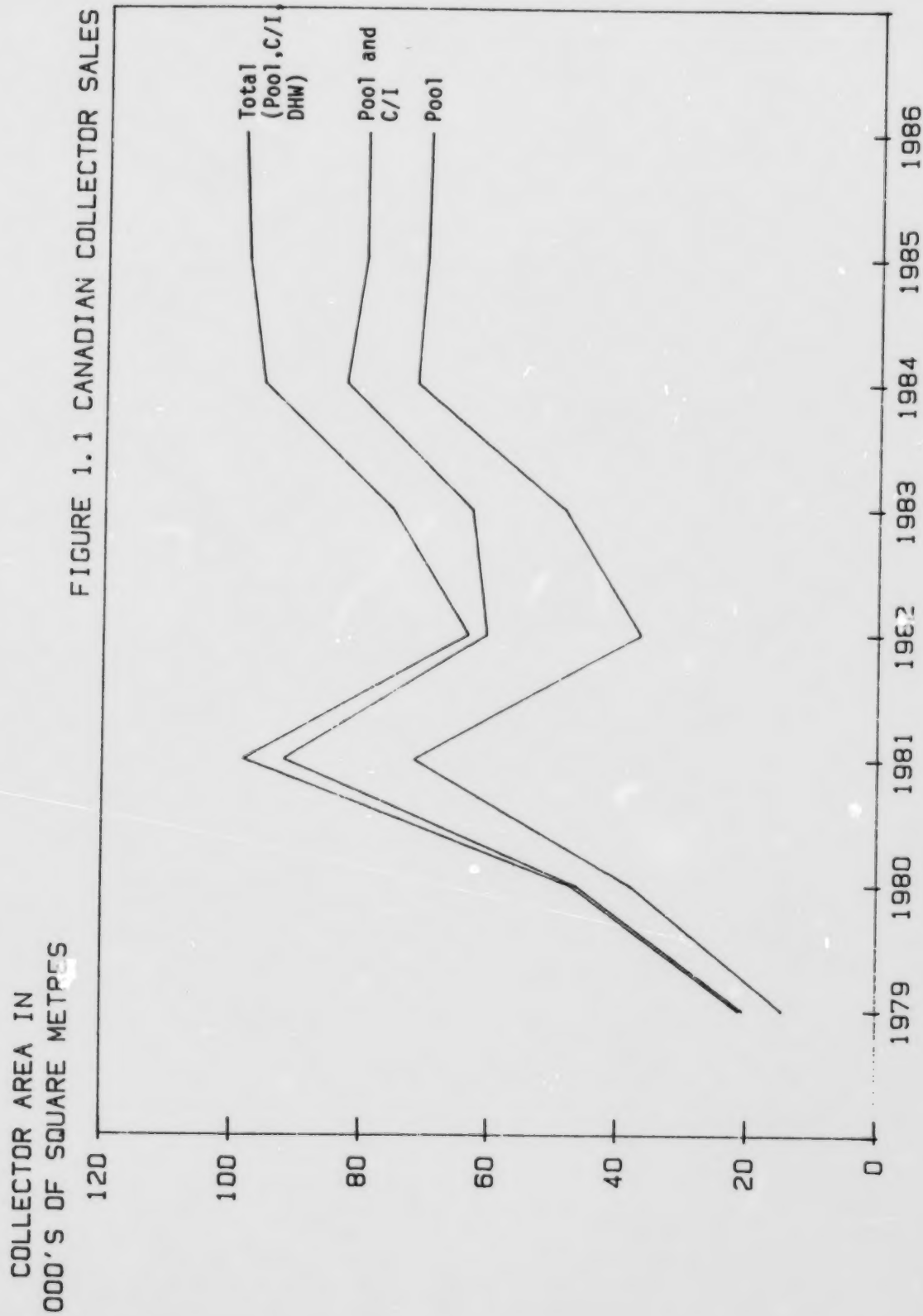
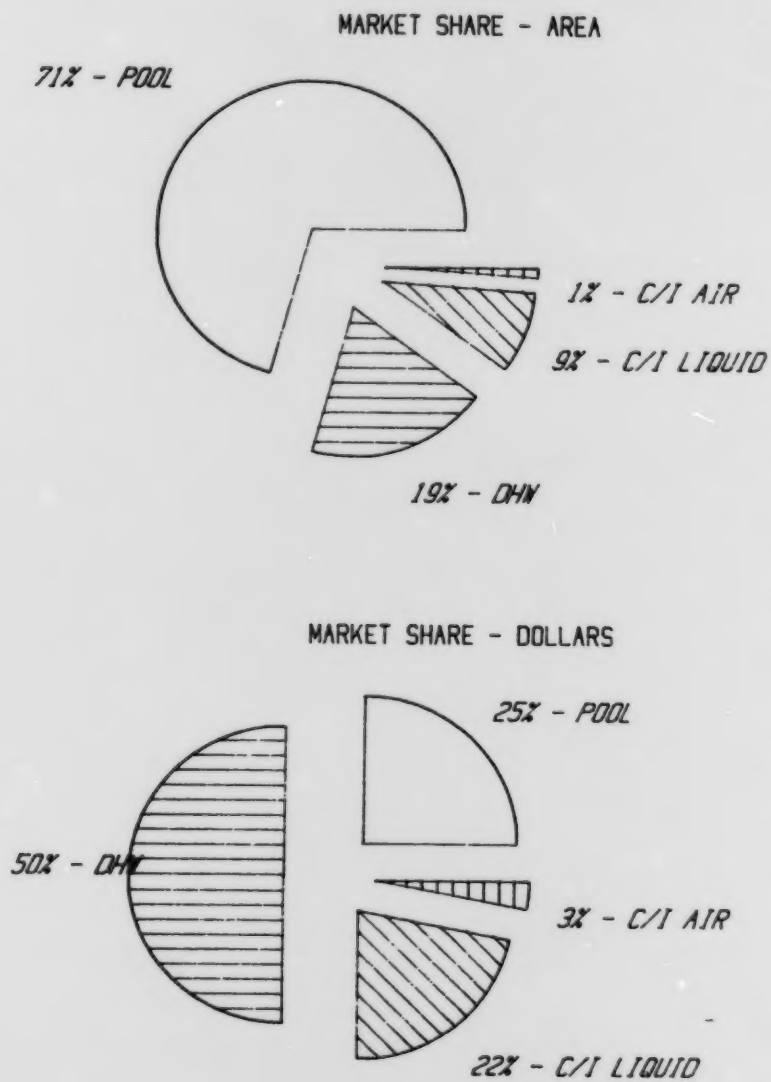


Figure 1.2 Canadian Solar Market Share by System Type



2. SOLAR HEATING SYSTEM COMPONENTS

Regardless of the system type, active solar heating systems generally contain the same components: solar collectors, collector support system, heat storage device, heat delivery device, fluid circulator and control system. These components are discussed in the following sections.

2.1 Solar Collectors

The solar collector is the heart of a solar heating system. This device converts solar radiation into heat. There are many different types of solar collectors, but the four most common are unglazed or flat-plate swimming pool, glazed flat-plate, evacuated tube and concentrating. Each of these types has been designed for different operating temperatures and is therefore best for specific applications (see Table 2.1). The solar collector must be matched to the temperature of the heating load. It is inefficient to use a swimming pool collector when high-grade heat is needed; conversely, it may be inefficient and costly to use a concentrating collector to supply low-temperature heat.

2.1.1 Swimming Pool Solar Collectors

The most basic solar collector is the unglazed swimming pool collector (see Figure 2.1). This collector consists of a black absorber plate, usually made of high temperature thermoplastic (or metal), through which a fluid is circulated. Normally, there is no insulation or glazing on the collector.

Swimming pool collectors are efficient only when the desired fluid temperature is no more than 10 Celsius degrees above the ambient (outdoor) temperature. At greater temperature differences, nearly all of the solar heat is lost to the environment. The most practical application for this collector is, as the name suggests, for heating swimming pool water during the summer months. Some swimming pool collector manufacturers offer a glazed version of their swimming pool collector.

Table 2.1 Operating Temperatures for Solar Collectors

<u>Type of Collector</u>	<u>Operating Temperature (°C)</u>						
	20	40	60	80	100	120	140 160
Swimming Pool							
Flat Plate							
Evacuated Tube							
Concentrating							
	low temperatures		medium temperatures		high temperatures		

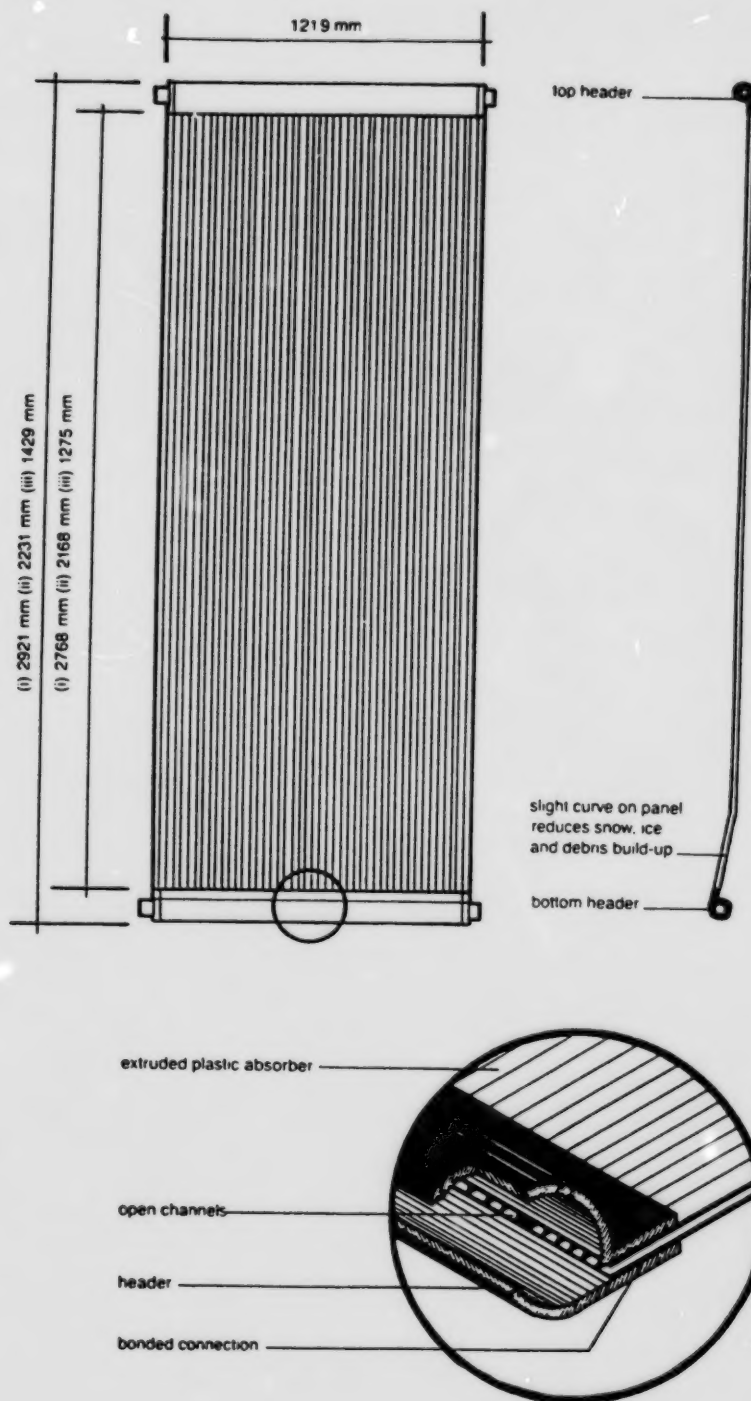


Figure 2.1 Typical Swimming Pool Solar Collector
(Courtesy CSIA)

Although the glazing reduces the amount of solar radiation striking the absorber plate, heat loss -- especially to the wind -- is reduced. A glazed swimming pool collector would be used to extend the swimming pool season earlier into spring and later into fall.

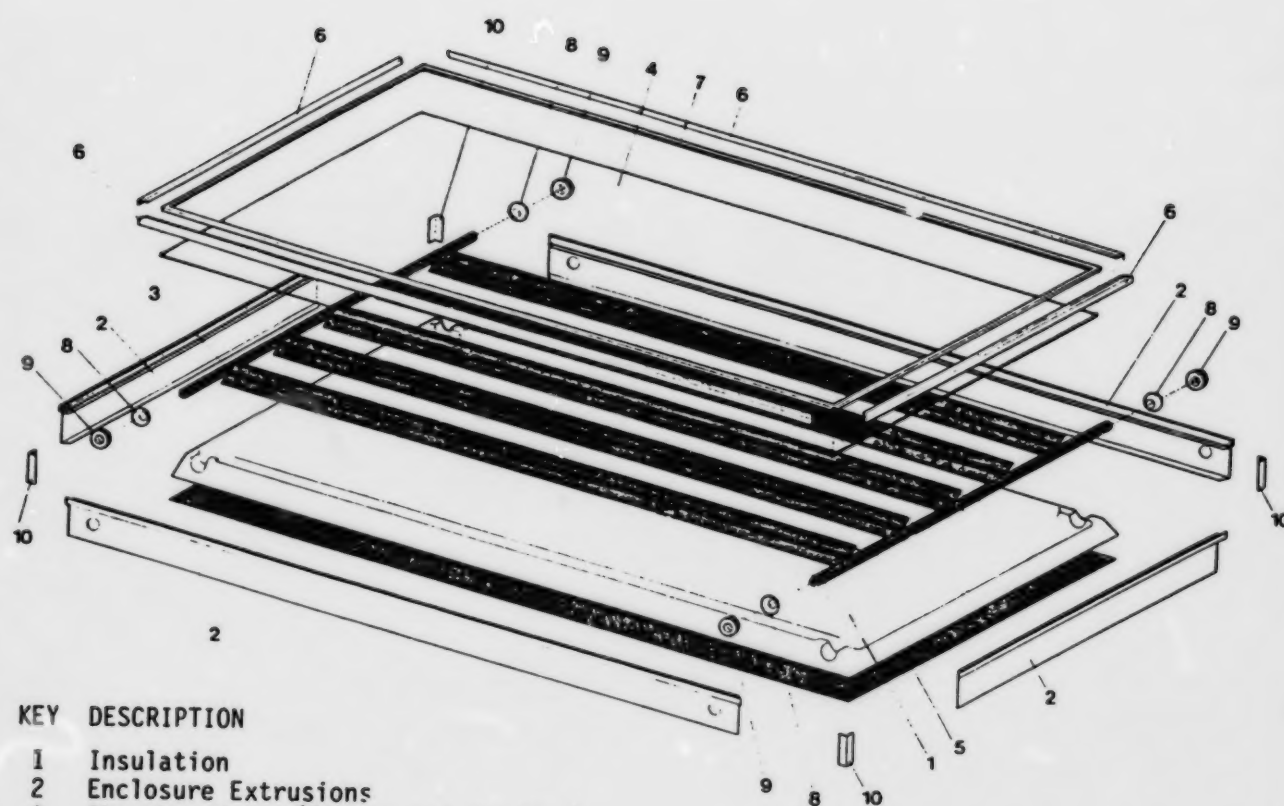
Commercially available swimming pool collectors are manufactured with ultra-violet (UV) inhibitors. These inhibitors increase the plastic lifetime to more than ten years.

2.1.2 Flat Plate Collectors

A flat-plate collector (see Figures 2.2 and 2.3) is used to achieve temperatures higher than those from a swimming pool collector. Flat-plate collectors can be efficiently used for temperatures of up to 70°C. The most widespread use of this type of collector is heating domestic and process hot water. A flat-plate collector consists of a metal absorber plate, glazing(s), and back insulation, all contained in a casing.

The purpose of the glazing is to transmit solar radiation yet minimize radiative and convective heat losses. Despite its relatively high cost, glass is the most commonly used glazing material because of its long service life. Low-iron (or water white) glass is generally selected over normal window glass because of its higher solar transmission (in excess of 90%). As with any large pane of glass, it is imperative that the glass be tempered to resist breakage from hail stones or thermal expansion and contraction.

Plastics have been used for glazings in some collectors to reduce costs. Materials used include fibreglass, rigid plastics (polycarbonate and acrylic) and films (Tedlar and Teflon). The main drawback to these glazings is their degradation when exposed to ultra-violet radiation. Film plastics are also susceptible to being torn by branches and high winds.



KEY	DESCRIPTION
1	Insulation
2	Enclosure Extrusions
3	Absorber Unit (Risers and Headers)
4	Cover
5	Backing Sheet
6	Top Clamp Extrusion
7	Gasket
8	Stop Flange
9	Grommet
10	Corner Bracket

Figure 2.2 Typical Liquid-Based Flat-Plate Collector
(Courtesy Solartech Limited)

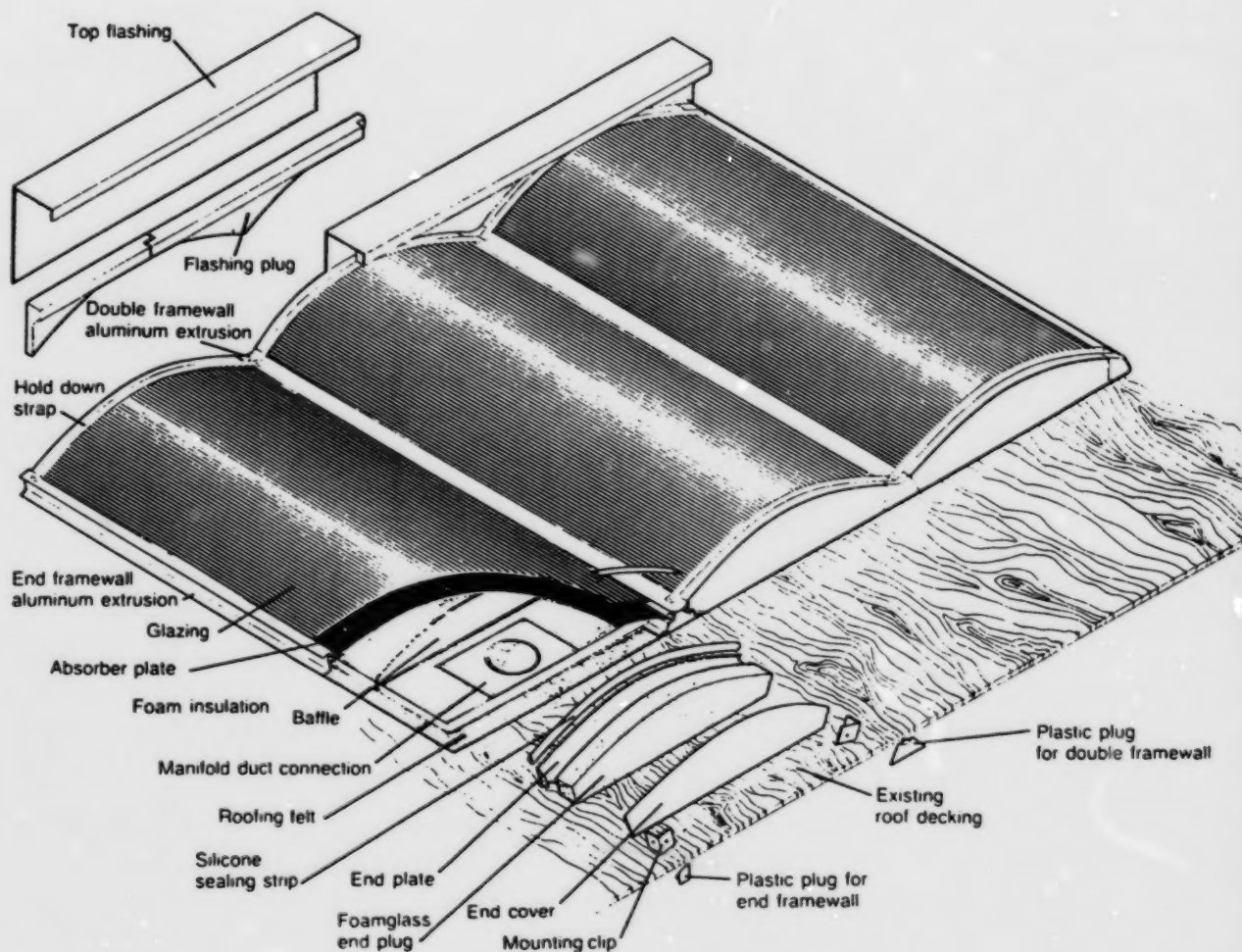


Figure 2.3 Typical Air-Based Flat-Plate Solar Collector
(Courtesy Solartech Limited)

Several years ago some collector manufacturers used two layers of glass to reduce heat loss; now, however, a single glazing is used in conjunction with a specially treated low-heat loss absorber plate coating (selective surface). A single-glazed, selective surface collector is generally lighter, less expensive, and approximately equal in thermal performance to a double-glazed collector.

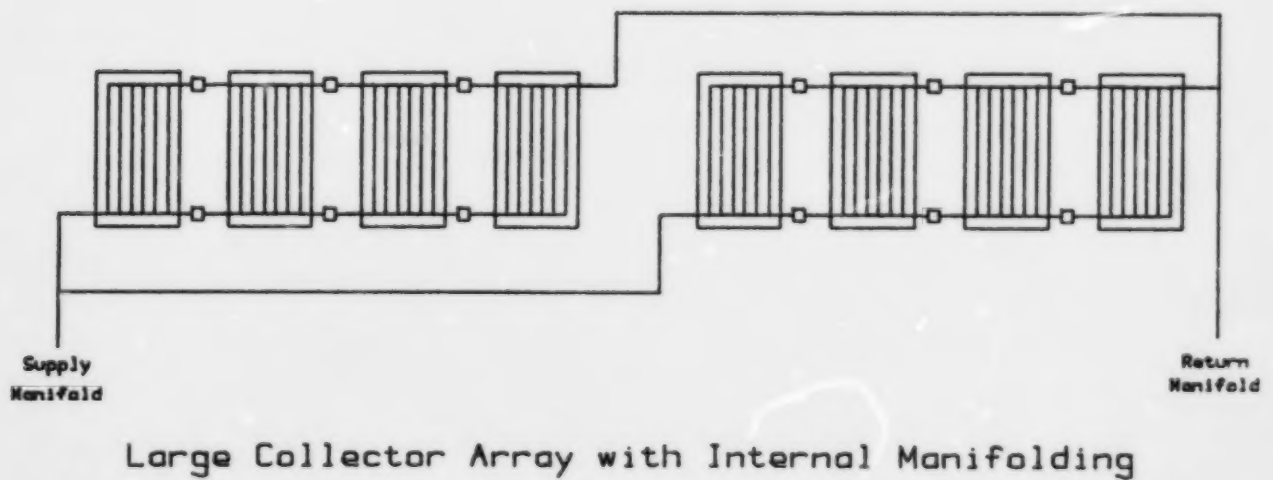
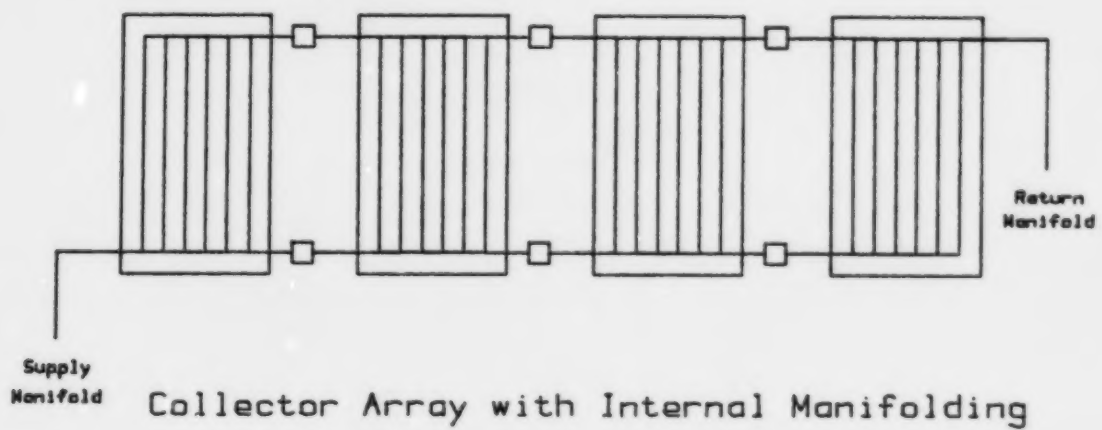
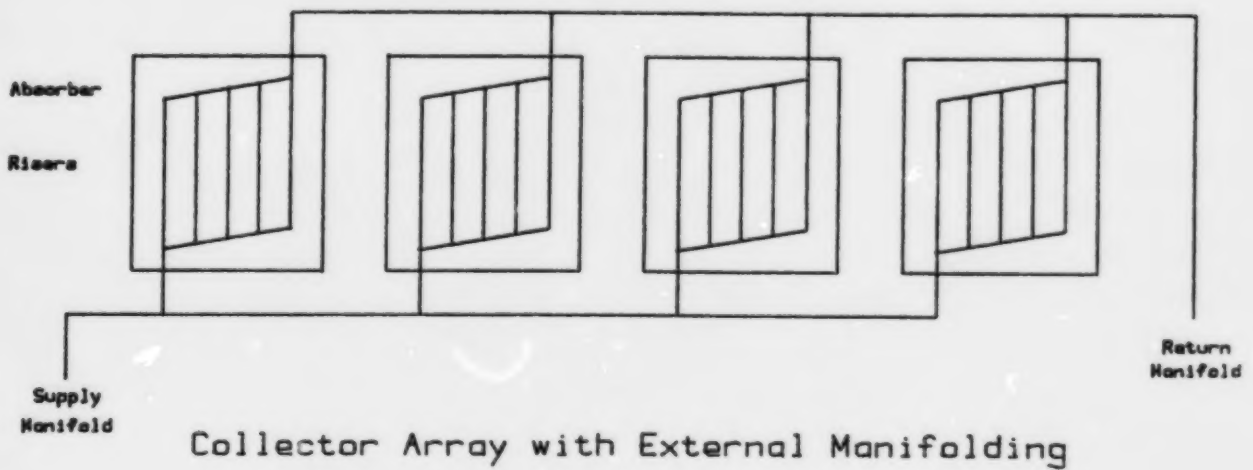
The absorber plate absorbs the solar radiation and transmits the heat to the circulating fluid. The absorber must be capable of withstanding temperatures of up to 200°C without any degradation. Although some experimental work is being done on plastic absorbers, the high temperatures necessitate a metal absorber (copper, aluminum or steel). The choice of absorber material is dependent on the heat transfer medium: air or liquid. (Air-based solar collectors are generally used when hot air is required. Liquid-based collectors are generally used when hot water is required.)

There are many different absorber designs for air-based collectors. Because air is a poor heat transfer medium, most absorber designs have the air in direct contact with 100% of the absorber plate. The advantage of full contact is that the thermal conductivity of the absorber plate is not important. Therefore, most air-based collectors use low-cost, low conductivity steel rather than higher-priced copper or aluminum. The absorber plates are usually either a flat sheet, slightly curved sheet (see Figure 2.3) or a corrugated sheet. The advantage of corrugated sheets is that there is a large area for heat transfer to the air. Some collectors use a fibre-matrix absorber made of fibreglass or aluminum (similar to a furnace filter): the large surface area in a fibre-matrix absorber means that it is extremely efficient in transferring heat. The disadvantage with this type of absorber is that a selective surface cannot be easily applied. One Ontario manufacturer uses a high temperature plastic bag as the absorber plate. This "air bag" is assembled with a glass cover on site.

There are two basic types of absorber designs for liquid-based collectors: tube-and-fin and roll-bonded. Roll-bonded absorber plates are generally made of aluminum, whereas in tube-and-fin absorbers, the tube is made of copper and the fin is made of copper or aluminum. To keep the costs down, the tubes or risers (each with its own fin) are spaced as far apart as possible. Top and bottom headers are connected to the risers (see Figure 2.2). Because of the high thermal conductivity of the copper fin, tubes can be spaced up to 15 cm apart with little loss in performance. The channels in an aluminum roll-bonded absorber are placed closer together because of aluminum's lower thermal conductivity. A Canadian manufacturer produces an absorber of copper tubes encapsulated within the aluminum fin. The absorber is shipped in rolls to collector fabricators who "inflate" the copper tubes with compressed air. This product is used by two Canadian collector manufacturers, and is used widely throughout the United States. With the advent of low-flow systems (see Section 3.2.1) some manufacturers are using a serpentine absorber. This absorber consists of a single riser "snaked" back and forth across the absorber plate. Because of the low flow rate used in these absorbers the pressure drop is not excessive.

An important consideration in the design of absorbers is how several collectors will be connected together. There are two basic approaches: internal and external manifolds (see Figure 2.4). External manifolds require that two pipes be installed: a supply pipe across the bottom and a return pipe across the top. Each collector must be connected to these pipes. This technique requires a great deal of site work and materials (pipe, fittings and insulation). Internal manifold collectors are much easier and cheaper to install, as the manifolds are included in manufacturing. The only disadvantage with internal manifolding is that the number of collectors that can be connected together is limited by the size of the manifold. Most internal manifolds allow up to six collectors to be connected together although some larger designs allow connection of up to 30 collectors. Serpentine collectors must either be connected in series or with external manifolds.

Figure 2.4 Internal and External Manifolds



An Ontario collector manufacturer has designed a collector which requires only one manifold. These collectors make use of a heat pipe inside the collector to transfer heat from the absorber to the top header pipe; no bottom manifolding is needed (see Figure 2.5).

Ultimately, the thermal performance of the absorber is limited by the optical properties of the coating: ideally, the absorber coating of surface would have high solar radiation absorption and low thermal (or infra-red) radiation emission. In recent years, reliable coatings have been developed that have high solar absorption and low thermal emission. These coatings, called "selective surfaces", consist of a thin film of black metal with a shiny metal substrate electroplated to the absorber. The most common selective surface internationally is black chrome with a nickel substrate.

To achieve high temperatures, it is essential that flat-plate collectors have back and edge insulation. The key factor in the selection of insulation is its ability to withstand temperatures of up to 200°C. Many insulators melt or "outgas" at high temperatures. Common fibreglass insulation, for example, contains phenolic binders to keep the fibre together. These binders would outgas and deposit on the glazing if used in a collector. There are, however, suitable binders that can be used in fibreglass to prevent outgasing. Most collectors use high-temperature fibreglass or isocyanurate insulation.

The final component of flat-plate collectors is the casing. The casing is usually constructed of aluminum or steel. An important part of the casing is the gasketing. Gaskets are needed to support the glazing and absorber plate while permitting thermal expansion and contraction.

Typical production cost for a flat-plate solar collector is shown in Figure 2.6 [3]. The most expensive part of the collector is the coated absorber. The relatively high cost of the side extrusions and header assembly has resulted in manufacturers producing larger and

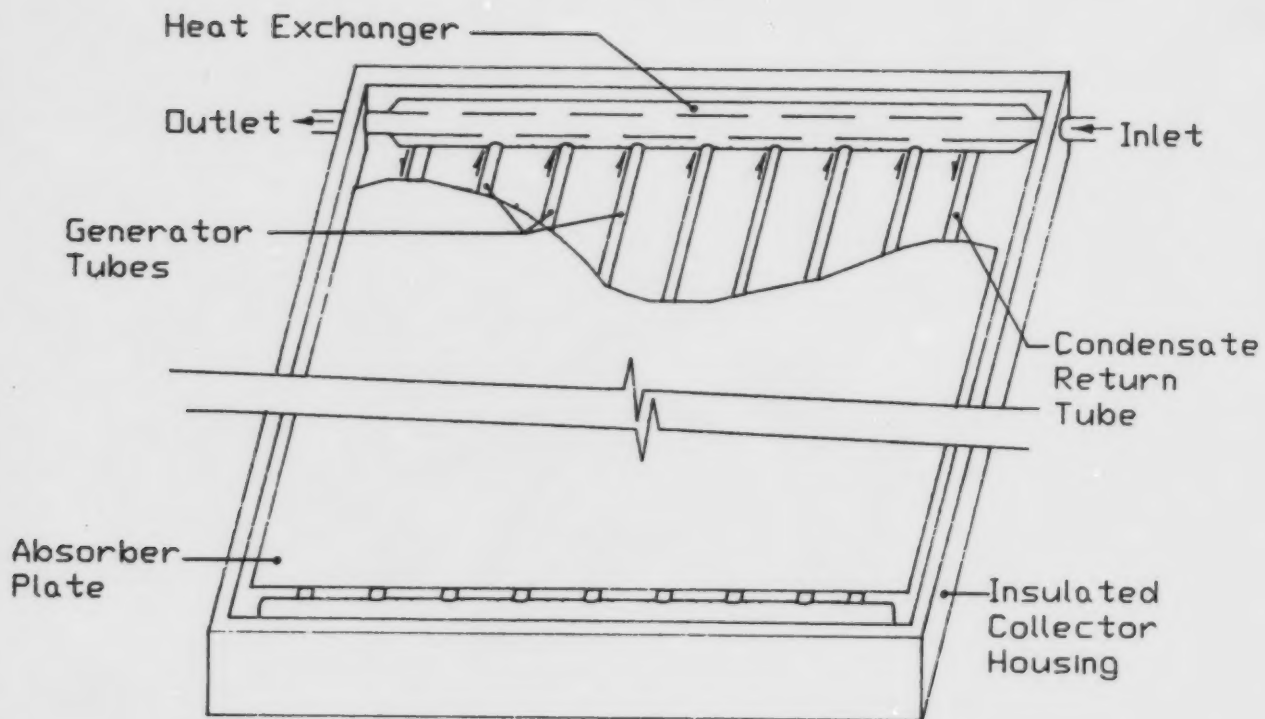
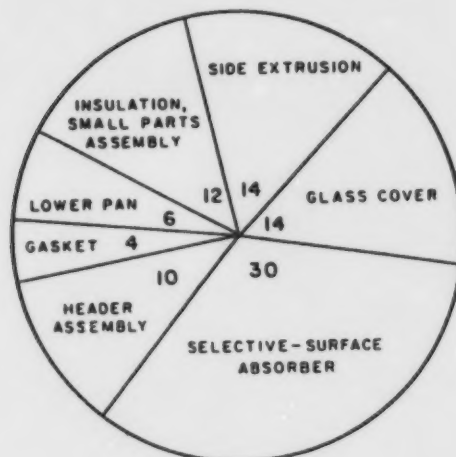


Figure 2.5 Thermal Diode Type Collector



ALL FIGURES IN \$/m²
TOTAL \$90/m²

Figure 2.6 Production Cost Breakdown for a Typical Flat-Plate Collector

larger collectors. A large site-assembled collector, referred to as the "mega-collector" has been used for several industrial water heating applications (see Figure 2.7). This collector is approximately 30% lower in cost on a per square metre basis. Site-assembled collectors have had problems, however, with quality control during assembly. Currently one manufacturer is investigating the potential for factory built mega-collectors.

2.1.3 Evacuated Tube Solar Collector

Evacuated tube solar collectors (see Figure 2.8) are used to achieve temperatures greater than those from a flat-plate collector. Evacuated tube collectors can efficiently generate temperatures of up to 150°C. These collectors are relatively expensive and have generally been restricted to medium-temperature process water applications, air-conditioning and desolination. They have the potential, however, to be used to supply lower temperature heat loads if their price drops as a result of mass production.

An evacuated tube collector consists of several evacuated glass tubes (much like fluorescent light tubes) mounted in parallel in a support frame. Inside each tube is an absorber plate with a selective surface. Because of the vacuum, no back or edge insulation is required. A metal bellows, or similar article, that expands and contracts is necessary to join the glass and absorber, because of the different thermal expansion rates of glass and metal.

The absorber plate details differ from manufacturer to manufacturer, but generally they all have the heat transfer fluid enter and exit from the same end. In one case concentric tubes are used; the fluid enters the inner tube and returns in the outer tube. A Montreal manufacturer's product uses a heat pipe, which consists of a sealed pipe with a contained fluid. When heat is applied, the fluid boils and travels up the tube. Heat is extracted at the top, causing the fluid to condense and fall back down.

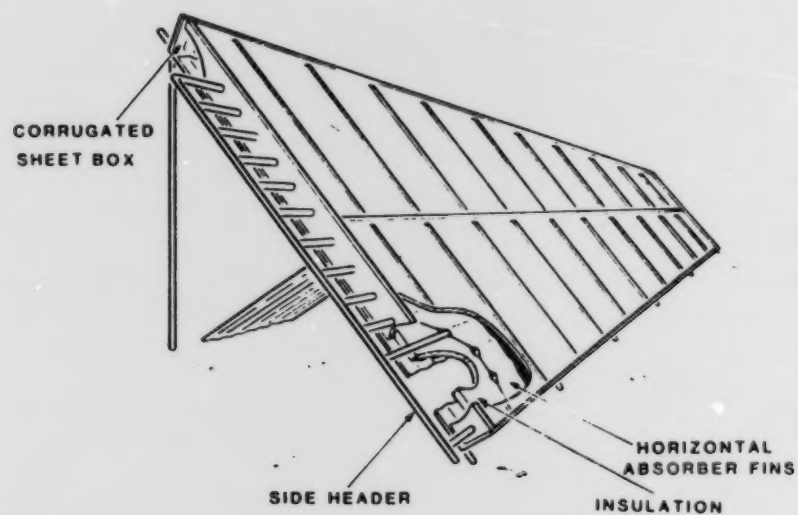
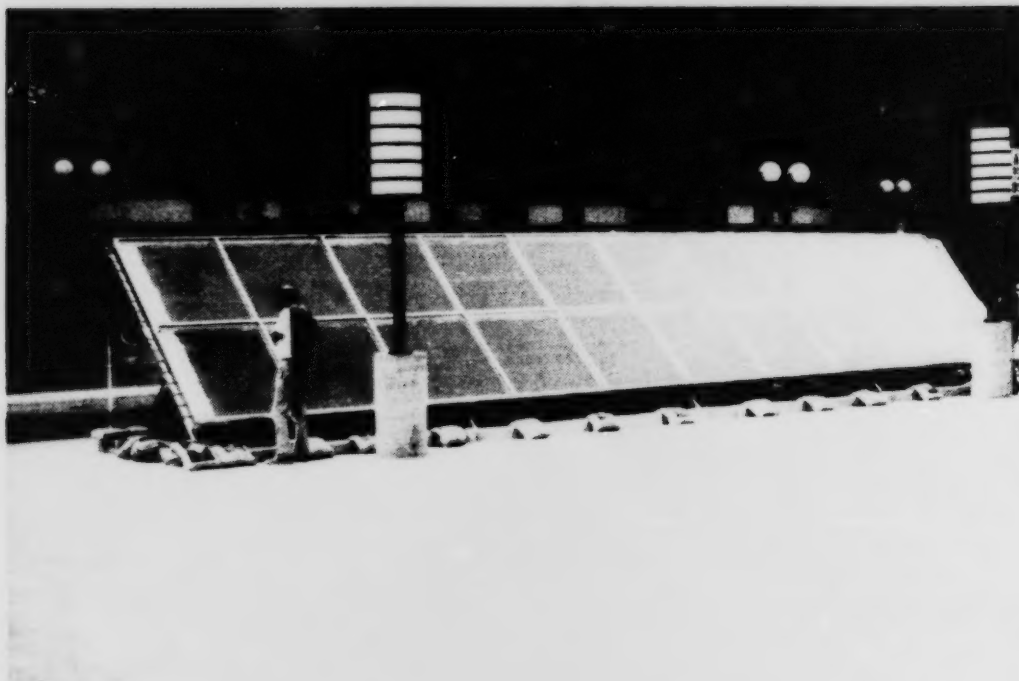


Figure 2.7 A Large Site-Assembled Collector for Industrial Applications

ITEM	DESCRIPTION
1	Collector tube
2	Manifold
3	End seal
4	"O" ring collector tube
5	Tube seal gasket
6	Vent tube seal bushing
7	Vent tube washer
8	Vent tube
9	Vent tube spring
10	Skin joiner
11	34.9 mm O.D. solder wrot copper cap
12	28.5 mm O.D. solder wrot copper cap
13	End cap skin
14	4.82 x 50.8 long self tapping screw
15	7.93 x 18 x 25.4 mm long s/steel hex. H.D. screw
16	Reflector assembly
17	Support channel
18	7.93 s/steel flat washer
19	4.76 pop rivet (stainless steel)
20	Tie rod
21	Tie rod bushing
22	6.35 plain washer
23	6.35 hex nut
24	Top mounting bar
25	Tube support cap
26	4.76 pop rivet (stainless steel)
27	Tube thermistor assembly
28	28.57 I.D. silicone hose
29	34.92 I.D. silicone hose
30	#20 lined s/steel gear clamp
31	#16 lined s/steel gear clamp

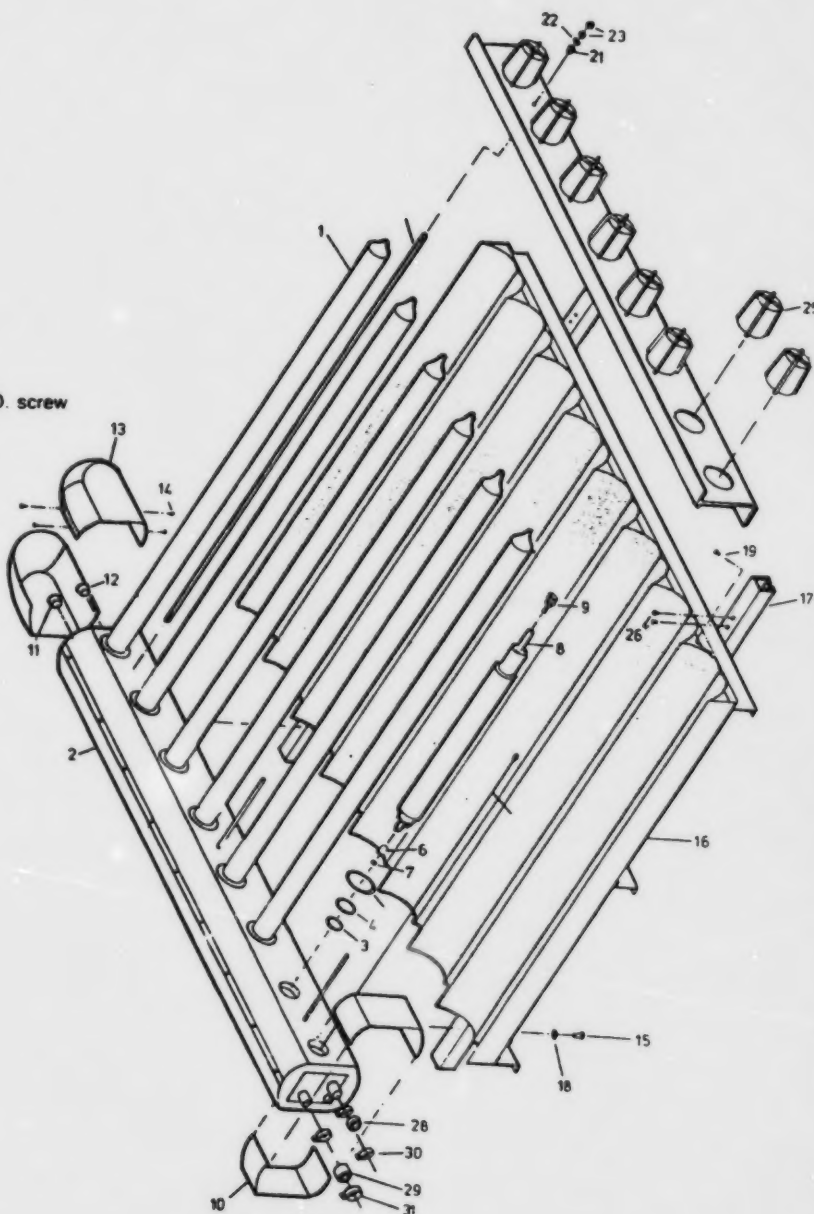


Figure 2.8 Typical Evacuated Tube Collector
(Courtesy Solartech Limited)

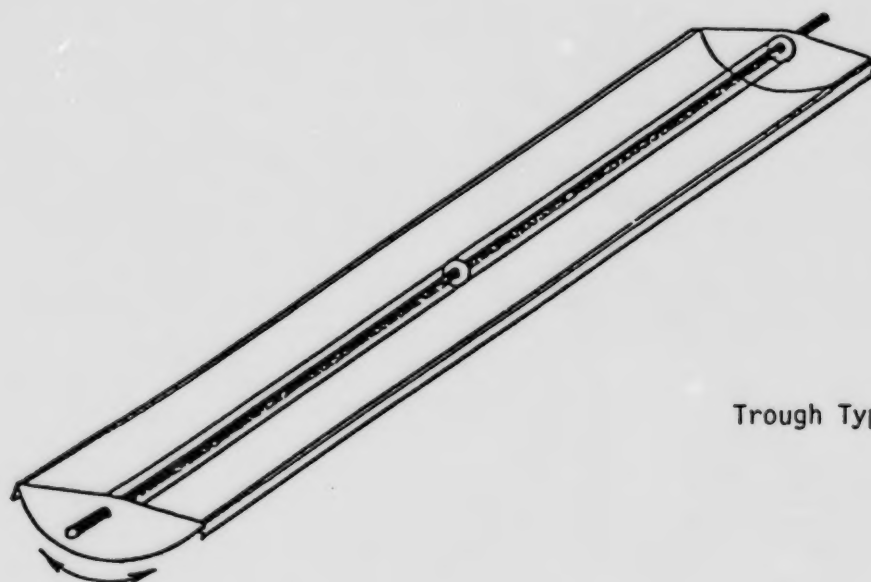
2.1.4 Concentrating Solar Collectors

Solar collectors that optically concentrate solar radiation before converting it into heat are called concentrating solar collectors. By concentrating solar radiation onto a small absorber area, the heat losses from the full collector are made relatively small. The greater the concentration, the greater the maximum delivery temperature: concentration ratios of several thousand have been attained with maximum temperatures of over 3000°C.

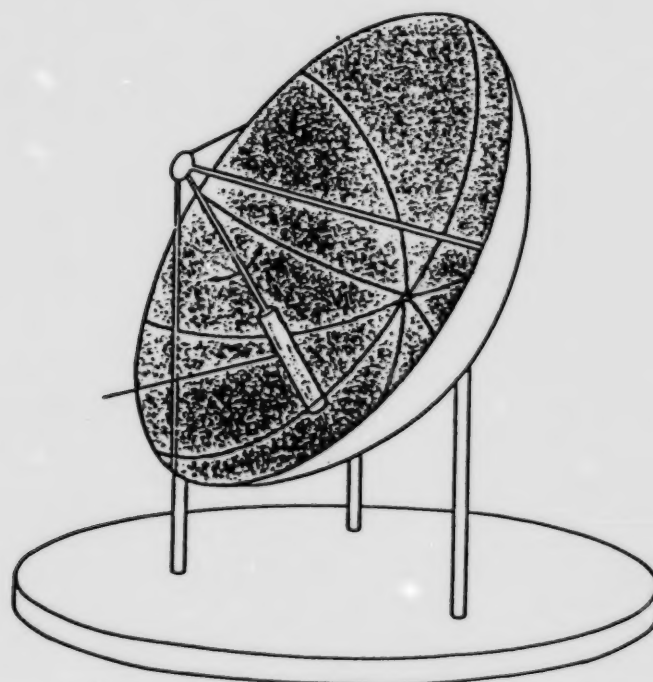
The two most common types of concentrating collectors are the trough (linear) and dish type (see Figure 2.9). These types of collectors can only use solar radiation that falls within a small angle band: solar radiation that is incident at off-angles will not be reflected onto the absorber. For this reason, concentrating collectors must track the sun and, even then, diffuse radiation cannot be collected. Trough-type concentrators follow the sun in one axis and dish type in two axes. The use of these collectors is restricted to clear locations, since they would collect very little solar radiation in cloudy locations. Concentrating collectors are not used to a great extent in Canada because, for most locations, diffuse solar radiation is over one-third of the total. The high cost and technical complexity of these collectors has restricted their use to high-temperature process water and steam generation in electrical power plants in sunny locations.

2.1.5 Solar Collector Heat Transfer Fluids

Air-based solar collectors use air as the heat transfer fluid. The advantage of using air is that it will not freeze, boil or become toxic; the disadvantages are the difficulty in eliminating air leakage, and air's low heat capacity compared to fluids for liquid-based collectors. There are four fluids that are used in liquid-based solar collectors: water, ethylene glycol, propylene glycol and silicone oils.



Trough Type



Dish Type

Figure 2.9 Concentrating Solar Collectors

The main disadvantage of water is its high freezing point. The only way that water can be used in collectors during the winter is by draining the collectors at night. This type of system is discussed in Section 3.2.

The glycols and silicone oils have considerably lower freezing points, thereby permitting use throughout the year. Silicone oils have not been used extensively in solar collectors, because of their high cost.

The glycols are the most popular collector heat transfer fluid. Ethylene glycol, if taken in large quantities, is toxic: Propylene glycol has a much lower toxicity, and as a result is the more widely used fluid (despite its higher cost). Both Ethylene and Propylene glycol, however, have a tendency to become acidic (and therefore toxic) when they boil. If glycol becomes acidic, the rate of corrosion in the system will rapidly increase. To prevent excessive corrosion, it is normally recommended that the glycol be checked each year and replaced every three to four years.

The problem of toxicity of solar collector fluids has resulted in some manufacturers using a double-walled heat exchanger (see Section 4.4). The toxicity problem should, however, be taken in context with the solar application. Non-potable water solar heating applications such as space heating do not require any type of toxicity protection.

2.1.6 Characterizing Collector Thermal Performance

For a given fluid and flow rate the efficiency of a collector depends on solar radiation and on the temperature difference between the collector fluid inlet temperature and the outdoor temperature. As the temperature difference increases, collector heat loss increases, which means that less of the solar radiation is delivered to the circulating fluid. Therefore, maximum collector efficiency is achieved when the collector fluid inlet temperature is close to the outdoor temperature.

The opposite is true of solar radiation: as solar radiation increases, more energy is available to go to the fluid. Therefore, collectors perform best under conditions of high solar radiation and low temperature differences between fluid temperature and ambient air temperature.

Figure 2.10 shows a graph of a collector efficiency for different types of collectors. The various collector efficiency "curves" can be represented by an equation (referred to as the Hottel-Whillier-Bliss equation) of the form

$$\eta_c = F_R \tau \alpha - F_R U_L ((T_{ci} - T_a) / H)$$

where T_{ci} is the collector fluid inlet temperature

T_a is the outdoor or ambient temperature

H is the incident solar radiation

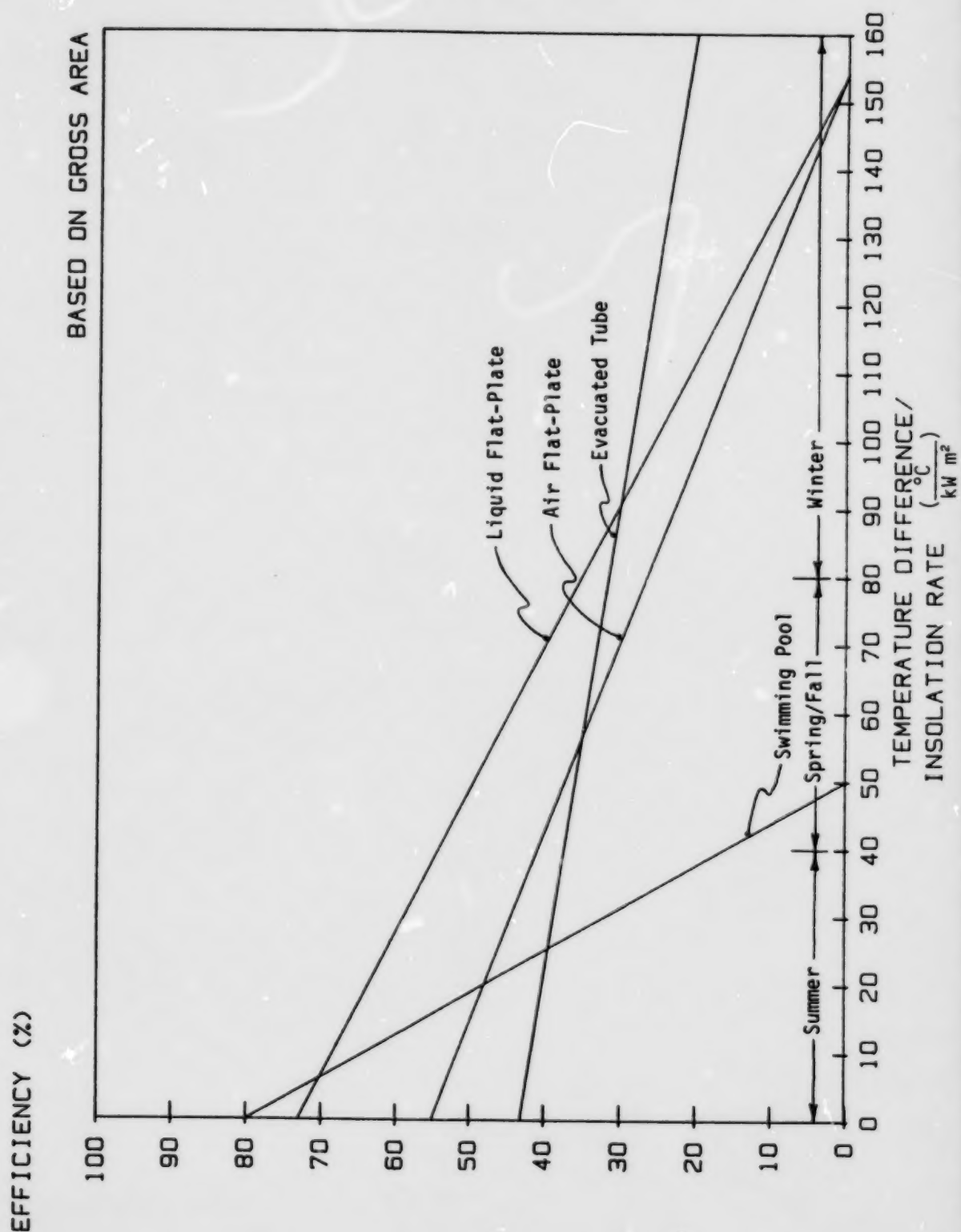
or, in terms of heat collected (Q_c),

$$Q_c = [F_R \tau \alpha H - F_R U_L (T_{ci} - T_a)] A_c$$

The variables $F_R \tau \alpha$ and $F_R U_L$ are referred to as the collector performance characteristics. The $F_R \tau \alpha$ term is a measure of the amount of solar radiation that is absorbed, and is equal to the intercept on the vertical axis. The $F_R U_L$ term is a measure of the heat loss from the collector and corresponds to the slope of the efficiency line. Ideally, a collector would have a high value of $F_R \tau \alpha$ (close to 1.0) and a low value of $F_R U_L$ (close to 0.0). As can be seen in Figure 2.10, these characteristics vary considerably, depending on collector type and design. To assist in the evaluation of collectors, a standardized test procedure, (CSA F378-M1985), has been established. The National Solar Test Facility experimentally determines the $F_R \tau \alpha$ and $F_R U_L$ according to that standard.

COLLECTOR EFFICIENCY CURVE

Figure 2.10



To compare the efficiency of different collectors, collector efficiency curves for the same flow rate can be placed on the same graph (as in Figure 2.10). The collectors can then be compared for any weather condition or time of year. The horizontal axis can be thought of as representing different times of the year. During the summer, the collector will be operating on the left end of the curve (i.e. close to the vertical axis): during the winter, the collector will be operating on the right end of the curve. The efficiency curves show that, during the summer, a swimming pool collector is more efficient than all of the other collectors. In the winter, however, the evacuated tube collector is the most efficient and the swimming pool collector will collect no heat. Thus, the selection of a collector depends on the temperature to be supplied and the time of year it will be operating.

If the collector efficiency curves are for different flow rates, the " F_R " terms can be adjusted to a common base using the formula:

$$F_{RT\alpha}(\text{adjusted}) = r \cdot F_{RT\alpha}(\text{test})$$

$$F_{RU_L}(\text{adjusted}) = r \cdot F_{RU_L}$$

$$\text{where } r = \frac{\dot{m}Cp_a (1 - \exp[-AF'U_L/(\dot{m}Cp)_a])}{(\dot{m}Cp)_T (1 - \exp[-A_C F'U_L/(\dot{m}Cp)_T])}$$

$$F'U_L = \frac{-(\dot{m}Cp)_T \ln[1 - F_{RU_L}(\text{test}) A_C/(\dot{m}Cp)_T]}{A_C}$$

where $\dot{m}Cp$ is the mass flow-specific heat product (a for adjusted, T for test conditions)

The Hottel-Whillier-Bliss equation has been modified to better represent collector performance. Some testing agencies characterize collector performance by including a second order heat loss term.

$$Q_C = [F_{RT\alpha} H - F_{RU_L} (T_{Ci} - T_a) - F_{RU_L2} (T_{Ci} - T_a)^2 / H] A_C$$

where F_{RU_L2} is the second order heat loss term.

Even this equation has been criticized for not adequately representing the performance of some collector designs (e.g. heat pipe and evacuated tube). A five parameter model has been prepared [4] of the form

$$Q_C = [AH - B(T_{Ci} - T_a)H - C(T_{Ci} - T_a) - D(T_{Ci} - T_a)^2 - E] A_C$$

where A,B,C,D,E are constants (A is equivalent to $F_R \tau \alpha$ and C is $F_R U_L$)

The main difference in this equation is the addition of the "E" term, or threshold power. In heat pipe collectors the "E" term represents the power required to initiate boiling in the pipe. If turbulators or boiling enhancers are not in the collector, the threshold power can be quite high.

The previous performance equations are used when the sun is normal to the collector. For off-normal incidence angles, the $F_R \tau \alpha$ term must be multiplied by the "incident angle modifier", K. For flat-plate collectors, this modifier is well represented by the equation:

$$K = 1 + b_0 (1/\cos \theta - 1)$$

where b_0 is a constant, dependent on collector design and θ is the angle of incidence.

For evacuated tube and curved glazing collectors, the above equation does not work well. For these collectors, efficiency can actually be better at non-normal incidence angles. To characterize performance of all collector types, testing agencies report collector performance at various horizontal and vertical incidence angles.

The evaluation of the collector performance equation is complicated in that solar radiation, outdoor temperature, fluid inlet temperature, and angle of incidence vary continuously throughout the year. To overcome this problem designers use computer simulation programs that calculate performance every hour based on historical weather data.

2.2 Collector Support Systems

The optimum tilt for solar collectors is not horizontal, but an angle between 30 and 60 degrees, depending on the application. If the building roof is not at the appropriate angle, a collector support rack or system may be warranted: collector support racks, however, are expensive. The designer should examine the trade-off between the loss in system performance from mounting the collectors at the roof angle and the installed cost of a collector support rack. For deviations of up to 30° from the optimum collector tilt angle and 40° from due south, it is probably more economical to mount collectors directly on the roof than to use a support rack. If the collectors are to be installed on a building with a flat roof, the designer has no choice but to use a collector support rack.

Collector support racks can be mounted on a flat or pitched roof, on a wall, or on the ground. In all cases, the designers should ensure that snow will not build up around the collectors. If the rack is ground mounted, the collectors must be supported above the maximum snow depth. If the rack is flat-roof mounted, the collector should be supported at least one metre above the roof surface (higher in snow belt areas). In some cases, collectors mounted on flat roofs will increase the wind loading on the roof beyond what the roof can support: therefore, a structural engineer should be consulted if a support rack is being considered. If the rack is mounted on a pitched roof, the back and sides of the rack should be enclosed or, alternatively, the collectors should be mounted one metre above the roof surface.

Collector support racks can be made from pressure-treated wood or from pipe or channels made of aluminum or steel.

2.3 Thermal Heat Storage

2.3.1 The Importance of Thermal Heat Storage

The purpose of thermal heat storage is to store solar heat during sunny days to be used in the evening or on cloudy days. There are, however, cases where thermal storage is not needed.

Whenever the heating load has a large thermal capacity or can accommodate temperature swings, an additional thermal storage unit would be redundant (examples of this type of load are swimming pools and warehouses). A thermal storage unit may be unnecessary if the heating load to be met by a solar system occurs only during daylight hours. For these latter systems, it is necessary to keep the solar contribution low (under about 35% of the total heating load) to avoid having excess solar heating capacity on sunny days.

2.3.2 Thermal Storage for Liquid-based Systems

Almost without exception, water is used as the thermal storage medium for liquid-based solar heating systems: its low cost and high specific heat make it the logical choice for solar heating systems. The high freezing point of water is not usually a problem, since most storage units are located in a heated space.

Water is stored in a large insulated storage tank, which is either pressurized or non-pressurized depending on the system design. Pressurized tanks are needed when the tank must maintain city water pressure (e.g. some solar domestic hot water systems). If a pressurized tank is needed, it must be constructed from steel; otherwise, the tank material can be either steel, fibreglass, concrete or polyethylene (depending on temperature).

As discussed in Section 2.1.6, maximum collector performance is achieved when the collector inlet temperature is a minimum. To achieve this requires the tank water be thermally stratified (i.e. hot water at the top, mains temperature water at the bottom). Stratification can be ensured by the proper collector flow rate and correct piping layout. The collector supply and mains water pipes should be connected to the bottom of the tank and collector return and load supply pipes should be connected to the top of the tank.

The flow of water to the collectors should be approximately 15 litres per hour, per square metre of collector [5]: faster water flow rates will result in less tank stratification.

The size of the storage tank is more dependent on the number of collectors than on heating load characteristics. The recommended water volume is usually 40 to 60 litres per square metre of collector [6]. The system performance over this range of storage sizes is fairly constant. Some systems have tried to store summer solar heat to be used in the winter: this requires a water storage tank approximately 100 times larger than for daily heat storage (5000 litres/square metre of collector). The high cost, high thermal losses, and increased potential for water leakage have discouraged most designers from using seasonal storage tanks.

The preferred location for the storage unit is indoors, so that heat losses are to the house and, if necessary, the unit can be easily serviced. Outdoor and buried storage tanks have higher heat losses, are difficult to service, and are more likely to be damaged.

2.3.3 Thermal Storage for Air-based Systems

The thermal storage medium for air-based systems is either rock or phase-change materials, with rock being the most common.

Figure 2.11 shows a typical rock bed thermal storage unit. Small rocks are contained in an insulated box, with plenums top and bottom for air flow. The box can be of wood frame or poured concrete construction.

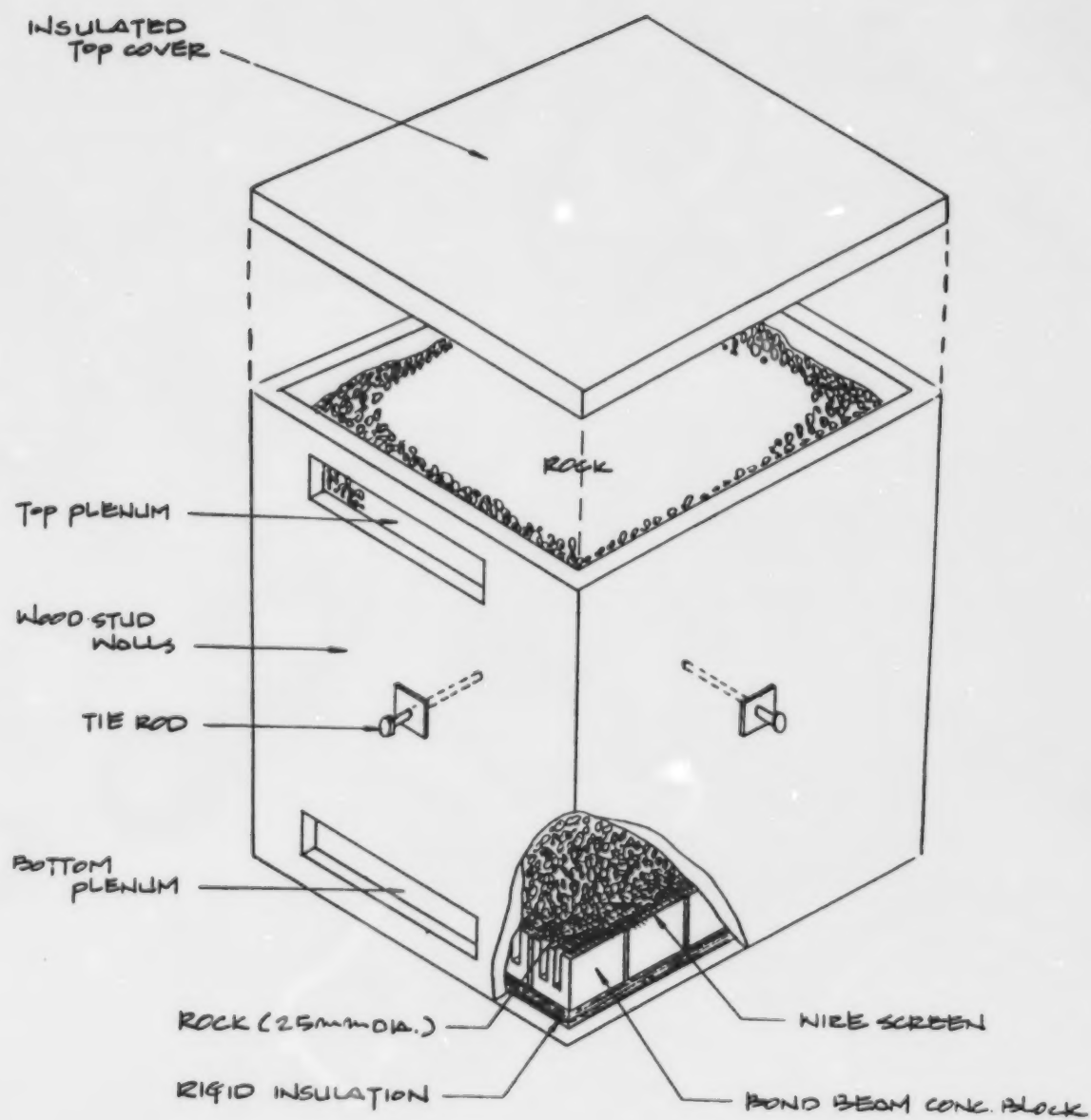


Figure 2.11 Typical Rock Bed Thermal Storage Unit

It is important that air be able to distribute evenly throughout the bottom plenum: this is usually done by creating an air space under the rock with bond beam blocks and a wire screen.

The main advantages of using rock as the heat storage medium are its low cost and wide availability: the main disadvantage is its low specific heat (approximately three times the volume of rock is needed to store the same amount of heat as water). The recommended size of a rock bed storage unit is approximately 0.2 cubic metres of rock per square metre of collector [6]. The rock material (other than volcanic) does not affect the performance of the rock bed.

Temperature measurements inside rock beds have shown that there is considerable temperature stratification (i.e. rocks in the upper section of the rock bed are much hotter than those in the lower section). When hot air is blown into the rock bed, a sharp thermal wave moves down through the bed. To remove heat from the rock bed, air is blown through the rock bed in the opposite direction. Reversing the air flow ensures that the hottest air is delivered to the heating load and rock bed stratification is preserved. The fan and ducting arrangements to accomplish reverse flow are discussed in Section 3.3.

In installations where interior space is restricted some designers have used phase-change materials as the heat storage medium. The most commonly used phase-change material is Glauber's Salt. This material changes from a solid to a liquid at 35°C. Several manufacturers sell plastic containers filled with phase-change materials. There have been problems with some phase-change materials breaking down after going through several hundred freeze-thaw cycles.

Researchers have been examining hygroscopic materials such as zeolite as a possible heat storage medium. These materials store heat by drying out, and heat is given off when water is re-added to the material. At present, however, several technical problems, such as material encapsulation, need to be resolved before this type of material can be used.

2.4 Heat Exchangers

Heat exchangers are needed in liquid-based systems to transfer heat from the collector fluid to the water in the storage tank (collector-side), and from the water in the storage tank to the load (load-side). Because no heat exchanger is 100% efficient (or effective), use of a heat exchanger results in a decrease in system performance. System designers always try to minimize the number of heat exchangers in a system. Ideally, a heat exchanger should have a large area for heat transfer and forced flow on both sides of the heat transfer surface.

Plate-type heat exchangers are commonly used in large solar installations. Their high heat transfer rate ensures a small performance penalty: their high cost, however, prevents use in small systems. The immersed-coil heat exchanger is widely used in small solar (domestic hot water) systems. A tank-in-tank heat exchanger is often used in small solar domestic hot water systems, especially drainback systems (see Section 3.2.1). The tank-in-tank heat exchanger consists of a tank containing water for the load inside a tank containing the collector fluid. The advantage of this heat exchanger is that heat is transferred continuously, and not just when the collector pump is operating.

A double-walled heat exchanger is sometimes used because of the toxicity of the collector fluid (see Section 4.4). Immersed-coil and shell-and-tube double-walled heat exchangers are commercially available.

2.5 Control Systems

Active solar heating systems require a control system to start and stop pumps and valves (or fans and dampers). A standard control system consists of two to four temperature sensors and one or more differential thermostats. Small solar heating systems are sold with a packaged control system, which plugs into any 120 Volt AC outlet. Larger systems require a dedicated electrical circuit and often a custom control system.

3. SOLAR HEATING SYSTEMS

3.1 Seasonal Solar Pool Heating Systems

3.1.1 System Descriptions

A typical solar heating system for an outdoor pool is shown in Figures 3.1 and 3.2. The system consists of swimming pool collectors (see Section 2.1.1), an automatic controller (with bypass valve) and a vacuum breaker. In most cases no solar pump is required: water is circulated through the collectors by the filter pump. If the collectors are mounted on the second story of the building, it may be necessary to replace the existing filter pump with a larger pump. Since the optimum collector slope for this application is 20 to 30 degrees, the collectors can be mounted directly on the roof. For new pools, the solar system is usually sized to meet the full heating load, thereby avoiding the need for an auxiliary heater. Sizing of solar heating systems is normally done by "rule-of-thumb": typically, collector area is equal to 50% of the pool surface area. If the pool is partly shaded or long piping runs are required, the installer might add an extra panel.

When the sun is shining, the filter pump passes the pool water through the filter, the solar collectors, and the pool heater (if used). If the solar system heats the water to the desired temperature, the pool heater does not come on. When the collector temperature drops below the pool temperature, the bypass valve is opened, causing the pool water to bypass the collectors. The water in the solar collectors drains, and air enters through the vacuum breaker.

It is important that all the collectors receive an equal flow of water. The standard installation technique is to connect collectors in parallel with the supply feed at the bottom. The piping should be connected in a "reverse return" arrangement (see Section 2.1). This means that, if the supply pipe is connected at the bottom left end, the return pipe should be connected at the top right end, and run the length of the array back to the left end.

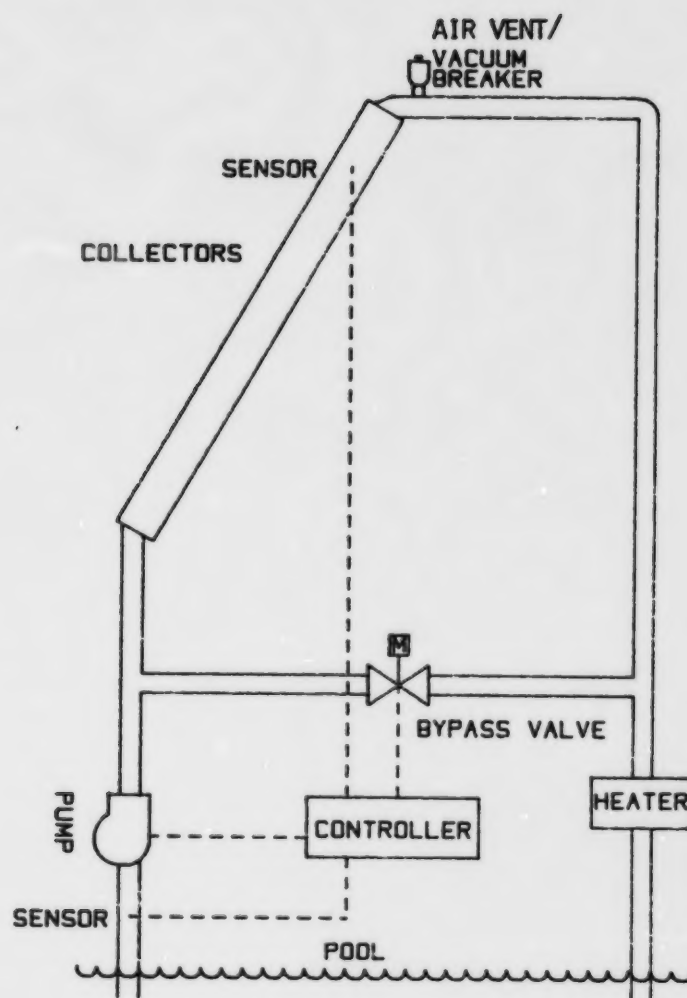


Figure 3.1 Typical Swimming Pool Solar Heating System Schematic

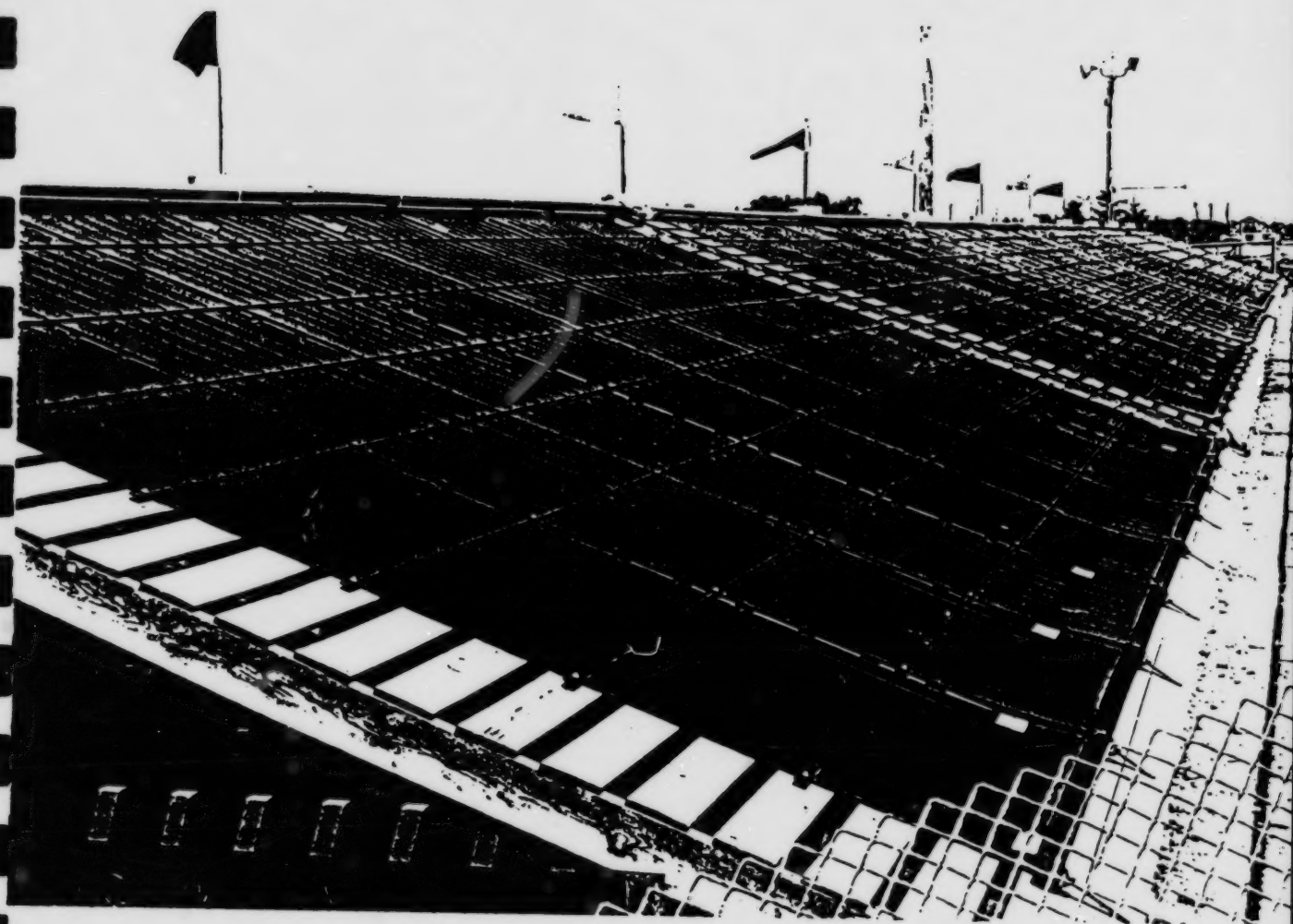


Figure 3.2 Largest Solar Pool Heating System in Canada
- Bingeman Park, Kitchener

3.1.2 Performance and Reliability

Because solar heating of seasonal pools has not been subsidized by the government, there has been very little independent performance or reliability assessment. Since most solar pool systems are sized to avoid using an auxiliary heating system, pool owners know how well the system is working only by tracking the pool water temperature. Although no in-depth study has been done, it would appear that the pool solar heating systems are working effectively and reliably. E.M.R. has initiated monitoring on two solar pool heating systems (located in Ontario and Quebec): results of that monitoring should be available in 1988. Computer simulations have shown that each season a solar seasonal pool heating system should deliver between 1.0 and 1.5 GJ per square metre of collector, depending on the length of the pool season.

3.1.3 Economics and Market

The economics of solar pool heating systems can be very attractive especially in new construction where the cost of a conventional heater can be avoided. A typical residential system of 18 square metres can be installed for \$2500 (a natural gas pool heater would cost approximately \$1600 to install). The \$900 premium for the solar system could be paid back in as little as three years. Commercial/institutional solar swimming pool systems have been more difficult to sell. The cost for these pools is often higher because of insufficient roof space, necessitating the use of wooden support racks.

Canadian swimming pool manufacturers, led by Ontario's Sunglo Solar, produce 70000 square metres of collectors annually, the equivalent of almost 4000 residential systems [1]. Of the Canadian production, approximately 40% is exported to the U.S. and most of the remainder is sold in Ontario.

3.2 Solar Domestic Hot Water Systems

3.2.1 System Descriptions

There are many solar domestic hot water system designs: the three receiving the most attention in Canada are drainback, antifreeze and seasonal.

Drainback SDHW Systems

Figure 3.3 shows a typical drainback solar domestic hot water system. In a drainback system, the solar heat transfer fluid is water at atmospheric pressure (although glycol is used sometimes), and is usually separated from city mains water by a heat exchanger. A control system regulates the collection of solar energy. A differential thermostat, measuring the temperature difference between the collector and storage, controls the pump operation. When the collectors are hotter than the storage, the pump turns on, and water flows from the bottom of the drainback tank, through the collectors and returns to the top of the drainback tank. Whenever the pump is turned off, water in the collector "drains back" by gravity into the pre-heat storage tank. If a heat exchanger were not used, city water pressure would prevent drainage of collectors and piping. The most commonly used heat exchangers are the immersed-coil and tank-in-tank (see Section 2.4).

When a hot water tap is opened in the house, city water pressure pushes water through the heat exchanger into the conventional tank, and finally delivers the water at the top of the conventional tank to the tap. If the water entering the conventional tank was heated to the desired hot water temperature, no auxiliary energy would be required.

To prevent scalding water at the taps, a tempering valve is placed in the hot water piping after the conventional water tank. If the water leaving the conventional water tank is too hot, the tempering valve allows cold water from the city mains to mix with the hot water.

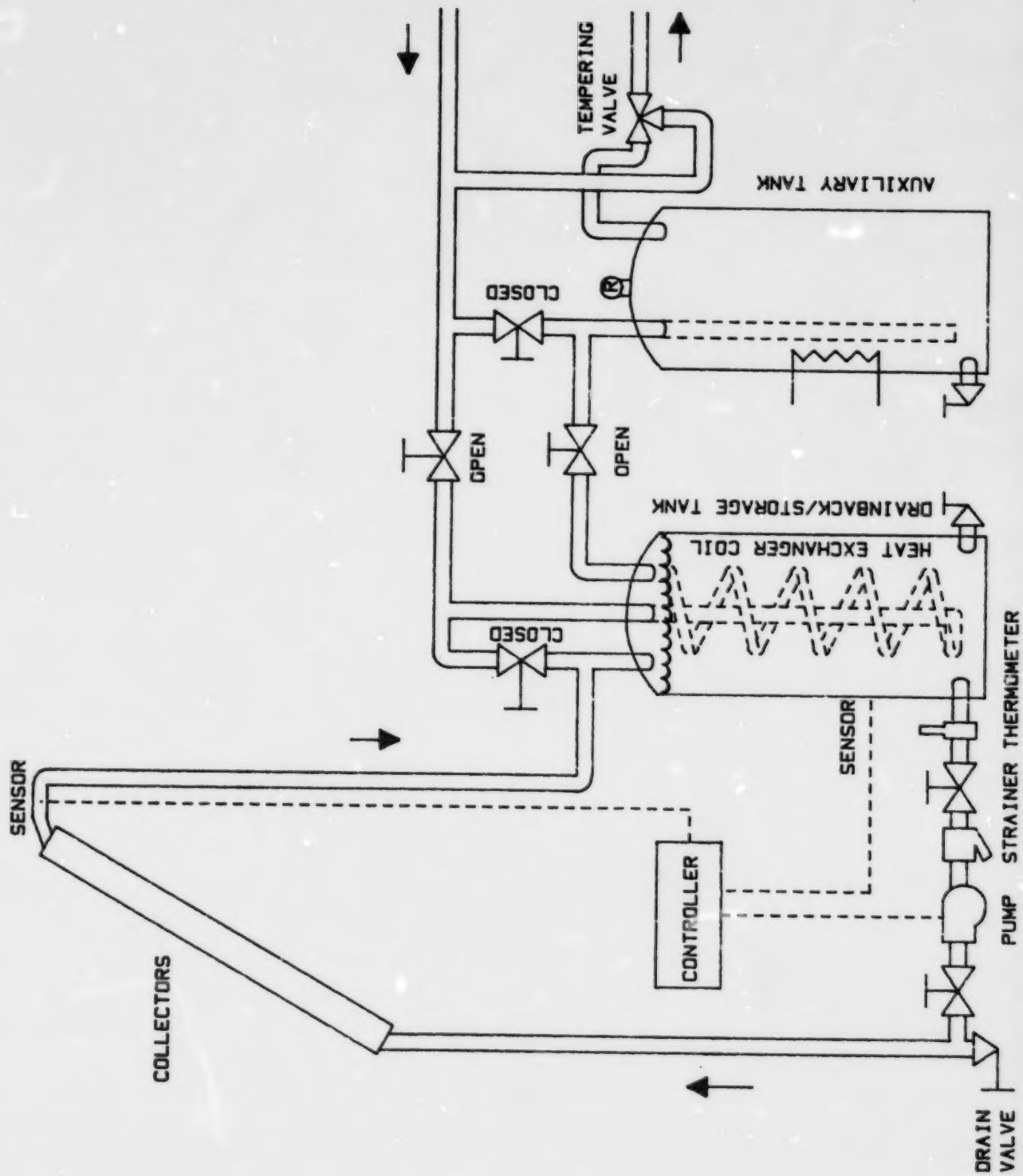


Figure 3.3 Typical Drainback Solar DHW System Schematic

A variation in system design is the size of the collector return piping. Some designers use a smaller diameter collector return pipe than supply pipe: this technique is referred to as syphon return drainback system. Alternatively, the system could have a return pipe equal to or larger than the supply pipe. In the syphon return system, when the pump comes on, the supply and return lines are completely filled with water and a syphon is created. If the return pipe is oversized, no syphon will be created. The advantage of the syphon return is that the pumping power requirements are reduced once the syphon is established. A syphon return system is, however, difficult to design for large systems with complicated piping runs.

An important design feature, often overlooked in early systems, is the avoidance of steam explosions. Under conditions of "no-flow" (i.e., stagnation) and high solar radiation, solar collectors can become very hot, in excess of 150°C. If the pump was turned on, the first slug of water from the drainback tank reaching the collectors would flash to steam. These steam explosions have caused collector piping to rupture. This problem was occurring at mid-day when the system was being re-started after being shut-down for morning maintenance. The simplest technique to avoid this problem is to attach a temperature snap-switch (set just below 100°C) to the collector. If the snap-switch opens, the pump would not be allowed to turn on. When the collectors cool down, the snap-switch would close and the system would be allowed to operate normally.

Drainback SDHW systems have two drawbacks: higher pump electricity consumption and potential for freezing. The drainback system pump must be able to overcome frictional losses and the height difference between the tank and the collectors. If the height difference exceeds eight metres, pumping power and energy consumption become too great in relation to the energy collected. If the water does not completely drain from collectors and piping when the pump shuts off, it could freeze and rupture the piping. To assist draining, piping is sloped a minimum of 1:50, and supported at least every three metres. Some designers have used antifreeze as the drainback fluid as additional protection from freezing.

Micro-flow

Although technically a drainback system, the micro-flow system has enough unique features to be classified as its own system. The main design principle behind this system is to reduce the collector flow rate to approximately 10-15 l/(hr·m²) so as to maintain a stratified storage tank. At this flow rate, the collector fluid will be heated to 50°C in one pass through the collector. A micro-flow system schematic is shown in Figure 3.4. By lowering the flow rate, the supply, return and collector piping can be reduced to 4 mm in diameter without excessive pumping power. The theory behind the system design is given in reference 8. Cost reductions are achieved by:

- placing flexible nylon supply and return piping and the collector sensor wire in a single rubber conduit at the factory,
- eliminating collector header pipes and using small riser tubes,
- eliminating most valves and pipe insulation.

Commercial designs use either a tank-in-tank or thermosyphon heat exchanger. A thermosyphon heat exchanger is similar to a shell-and-tube heat exchanger where the shell side fluid is pumped and the tube side (i.e. tank) fluid circulates by buoyancy effects. At present, the micro-flow system uses antifreeze as the collector fluid to avoid freezing problems.

Antifreeze SDHW Systems

Figure 3.5 shows a typical antifreeze (or sometimes called closed-loop) solar domestic hot water system. In an antifreeze system, the solar heat transfer fluid is some type of antifreeze (see Section 2.1.5), typically glycol. In this system, the heat exchanger contains the collector fluid, whereas the drainback system heat exchanger contains city mains water. The collector loop is completely filled with antifreeze and is never drained (except for maintenance). The pre-heat tank contains city mains water at city water pressure.

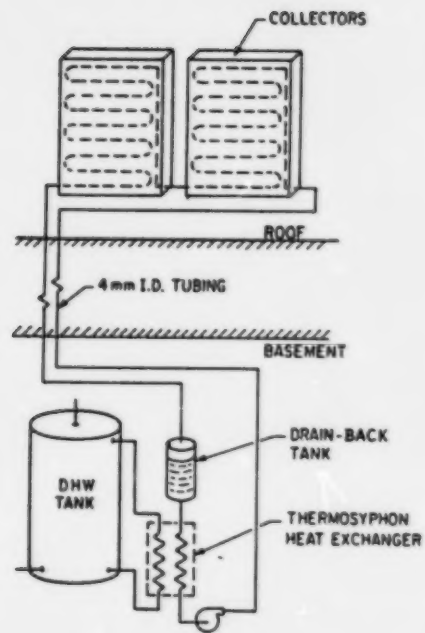


Figure 3.4 Micro-flow Solar DHW System Schematic and Piping

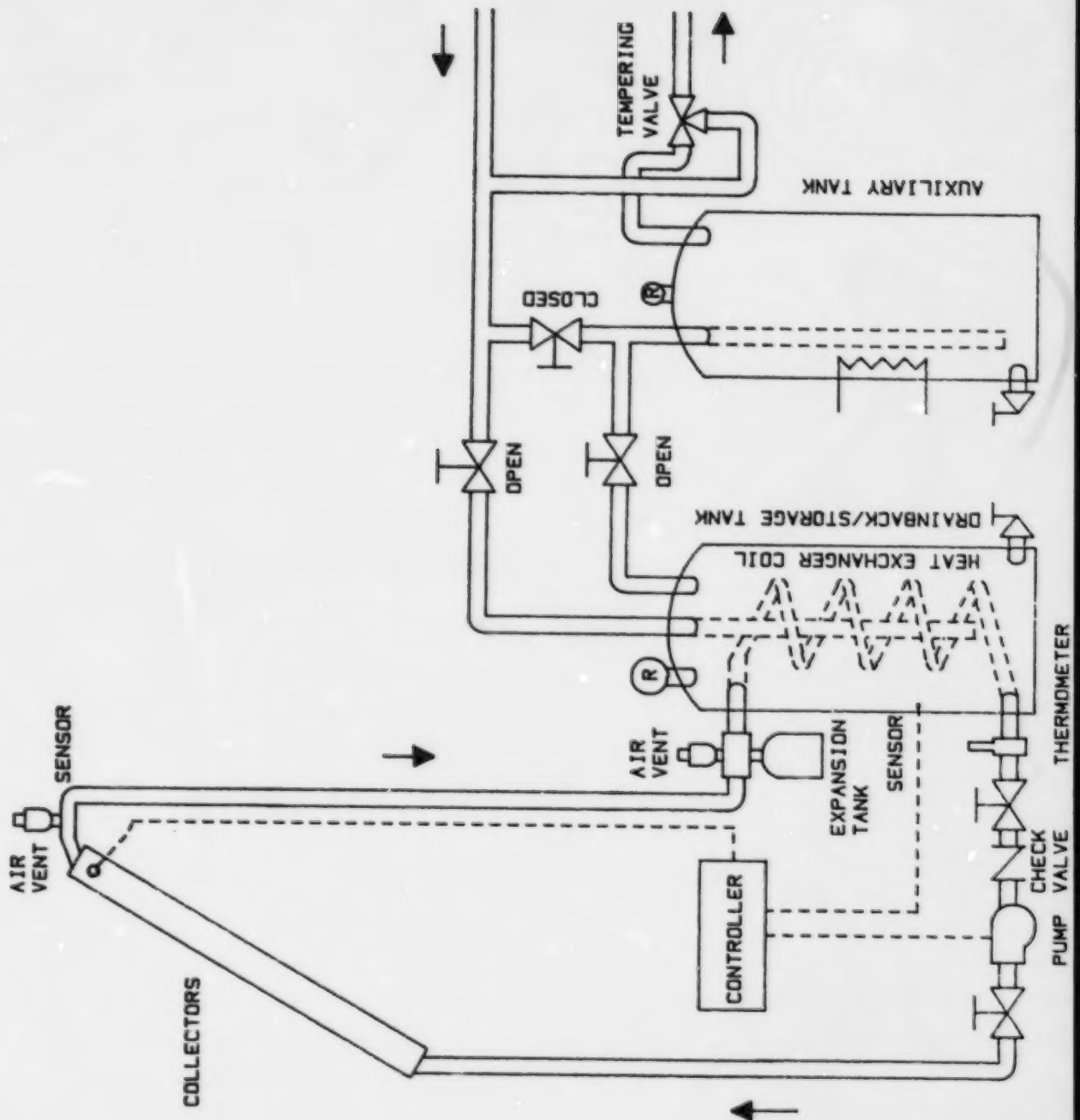


Figure 3.5 Typical Antifreeze Solar DHW System Schematic

Because the loop is closed, provision must be made for the thermal expansion and contraction of the antifreeze. An appropriately sized expansion tank and pressure relief valve will be able to maintain a constant pressure in the loop despite fluctuations in temperature. It is possible that, under conditions of "no-flow", high solar radiation, and warm ambient temperature, the glycol in the collectors could boil. This would cause the capacity of the expansion tank to be exceeded, forcing some of the glycol to be vented through the pressure relief valve. When the system cooled down, the displaced glycol would have to be re-added. The system should be designed for safe discharge of the boiling glycol from the relief valve and convenient re-fill when the system has cooled down.

As the collector fluid is heated, it will give up oxygen. This oxygen can accumulate as an air lock, blocking the flow of fluid. To prevent a build up of oxygen, an air scoop with an automatic air vent mounted on top is installed. An air scoop (air purger or air eliminator) consists of a series of baffles which separate the oxygen from the fluid. If air is present, a float in the vent lowers, opening a valve allowing the air to exit. A manual air vent is normally placed at the highest point in the loop to bleed off air when filling the system with glycol.

Antifreeze systems require several other valves for proper operation. A check valve must be installed in the collector supply line to prevent reverse flow at night. Drain and fill valves are installed across the check valve to fill the system with glycol. On the water side of the system, a temperature/pressure relief valve is installed on the pre-heat tank: this valve will dump water to a floor drain if the tank temperature reaches 100°C. A mixing valve is installed in the hot water piping after the conventional water heater, to temper the water to the desired temperature.

Some instrumentation is usually installed to enable the homeowner/installer to check on system operation. A pressure gauge allows the installer to accurately set the glycol loop pressure. A significant loss in pressure at a later date may indicate a leak or excess air in

the glycol loop. Thermometers in the collector supply and return lines will give an indication of how the system is working. Some designers include an elapsed time meter on the pump: the cumulative pump run time is an indicator of how much energy the system has collected.

The main advantage of the antifreeze systems is the reliability of freeze-protection. If the glycol is checked once a year, there should never be a problem with freezing. Besides the additional capital costs, the main disadvantage of antifreeze systems is the additional maintenance. Glycol must be checked each year and replaced every three years. If glycol is discharged through the pressure relief valve, the system has to be topped up promptly to avoid corrosion caused by the remaining glycol re-acting with the oxygen and turning acidic. If the system is not to be used for an extended period (e.g. holidays), then the glycol should be drained or the collectors covered with a tarp.

Seasonal SDHW Systems

There are three types of seasonal SDHW systems that have been used in Canada: thermosyphon, re-circulation, and batch. The most common SDHW system on a world-wide basis is the thermosyphon system (see Figure 3.6). In warm countries such as Israel almost every house has a thermosyphon SDHW system. Batch water heaters are also becoming popular in warm climates. In Canada, the need for freeze-protection has restricted the use of these systems. Several Canadian manufacturers offer an inexpensive batch or thermosyphon system for summer cottage use.

In a standard thermosyphon SDHW system, the collectors and storage tank are filled with water at city mains pressure. The fundamental principle of thermosyphon operation is that the collector fluid flows by density difference (i.e., it is not pumped). To accomplish thermosyphon flow, the storage tank must be installed above the solar collectors. When the water in the collectors becomes warmer than the tank water, the collector water will rise and the tank water will fall. The thermosyphon system flow rate depends on the height difference between the collectors

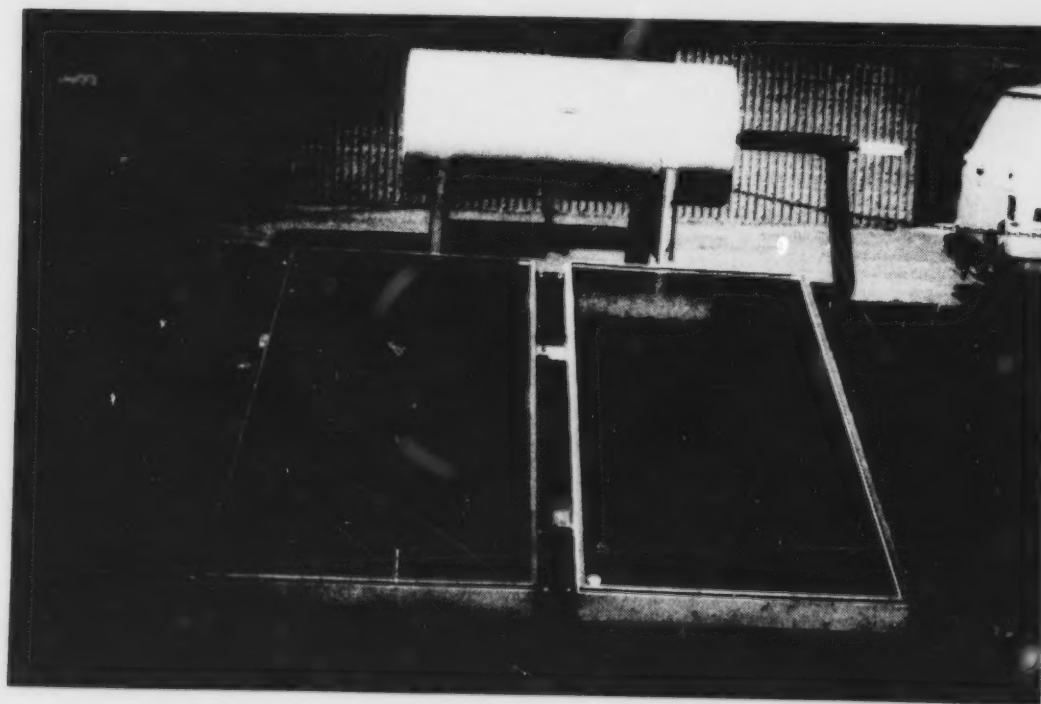
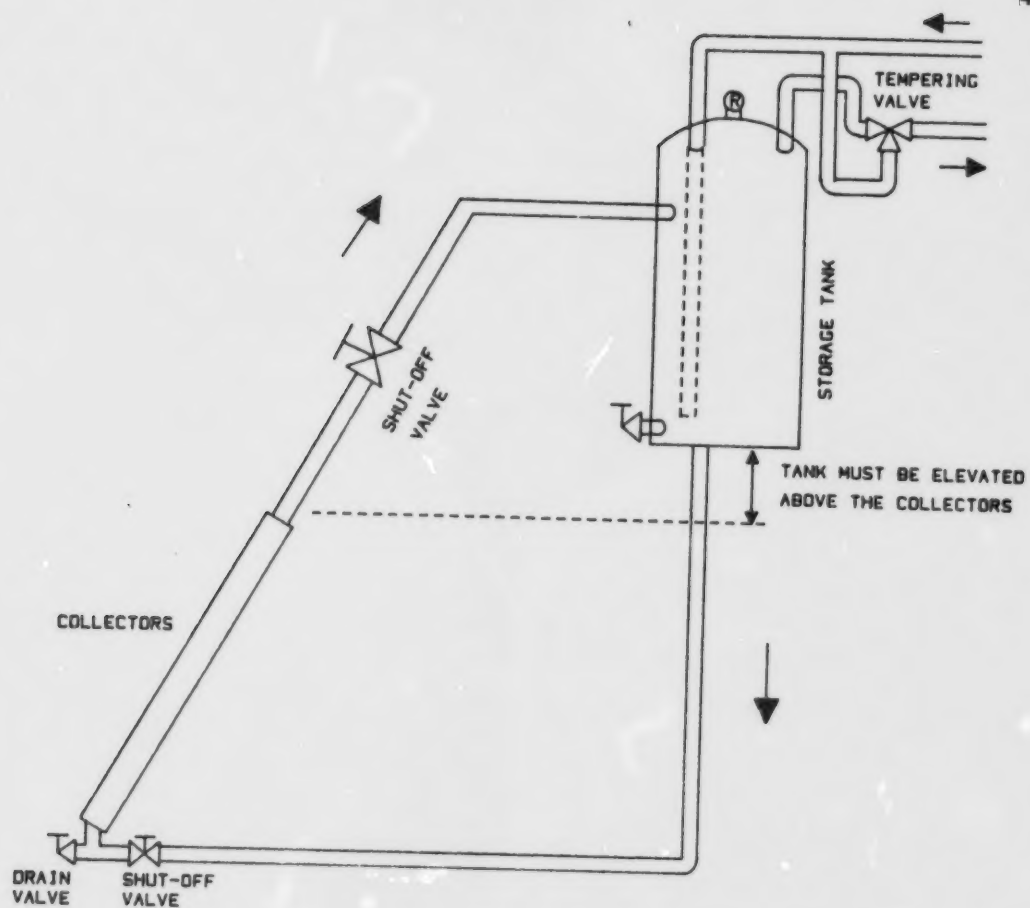


Figure 3.6 Typical Thermosyphon Solar DHW System

and tank, the frictional resistance of the piping, and the density difference between the collector water and storage water. A typical thermosyphon system would have a flow rate of approximately 15-20 l/(hr·m²), one-third that of a pumped system. The main factor affecting flow rate is the collector pressure drop. Reference 8 discusses proper thermosyphon system design. In a batch (or integral collector-storage) solar DHW system, the storage tank is mounted inside the collector (see Figure 3.7). The appeal of these seasonal systems is their simplicity and low cost. They do not require a pump, controls, heat exchanger, expansion tank, or most of the valves associated with other SDHW systems. The only valves in the system are a mixing valve in the hot water line to the house, a pressure relief valve on the tank, and a drain valve.

In re-circulation systems, no heat exchanger is required; mains water is circulated directly through the collectors (see Figure 3.8). When there is a danger of freezing, the pump circulates water through the collectors. This type of system is particularly well suited to low heat loss or thermal diode type collectors.

In cold climates, a standard thermosyphon system cannot be used all year, because of the danger of water freezing. In locations where there are only a few occasions of freezing temperatures, a drip valve, small electric heater, or heat tape at the bottom of the collector can prevent freezing. For increased reliability, many designers will use several methods of freeze protection each protecting a different part of the system. For colder locations, an antifreeze thermosyphon system must be used.

An antifreeze thermosyphon system (see Figure 3.9) is similar to an antifreeze pumped system, except that there is no pump or control system and the storage tank is mounted above the collectors. The collector loop is filled with glycol to permit year round use without freezing. One drawback of using glycol in the collector loop is the lower flow rate (glycol is much more viscous than water, especially at low temperatures).

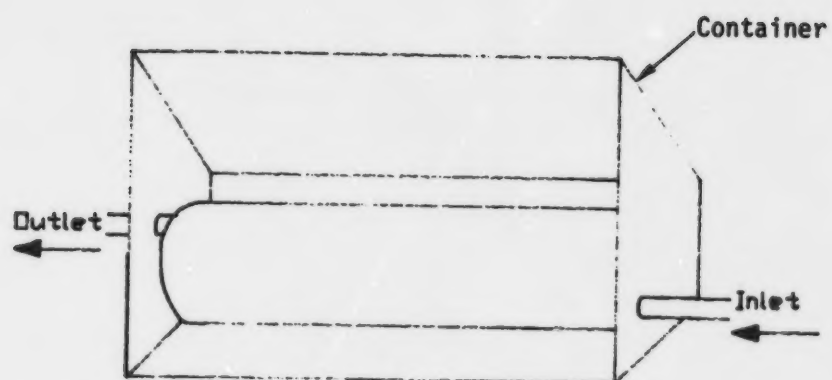


Figure 3.7 Batch Solar DHW System

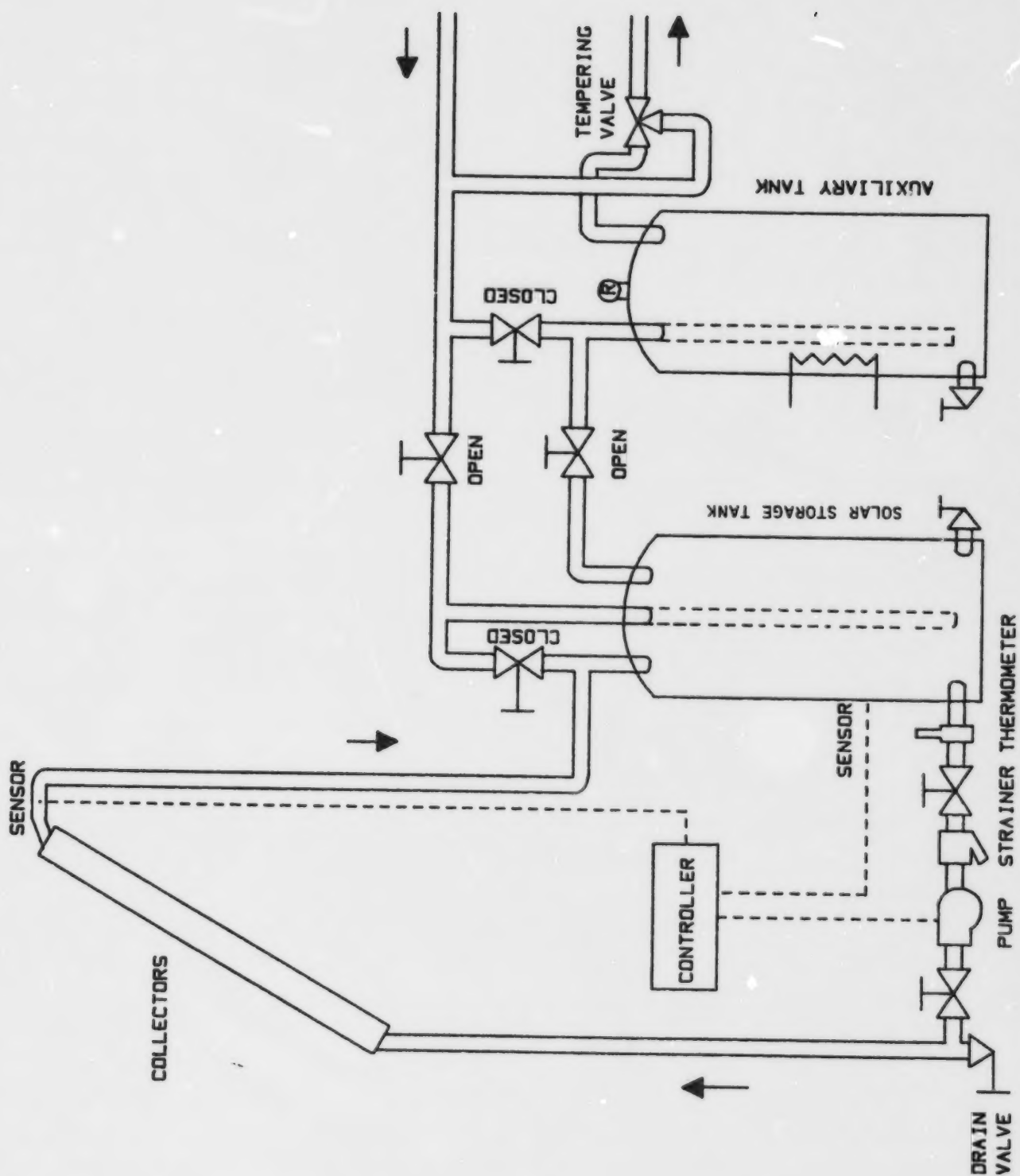


Figure 3.8 Typical Recirculation Solar DHW System

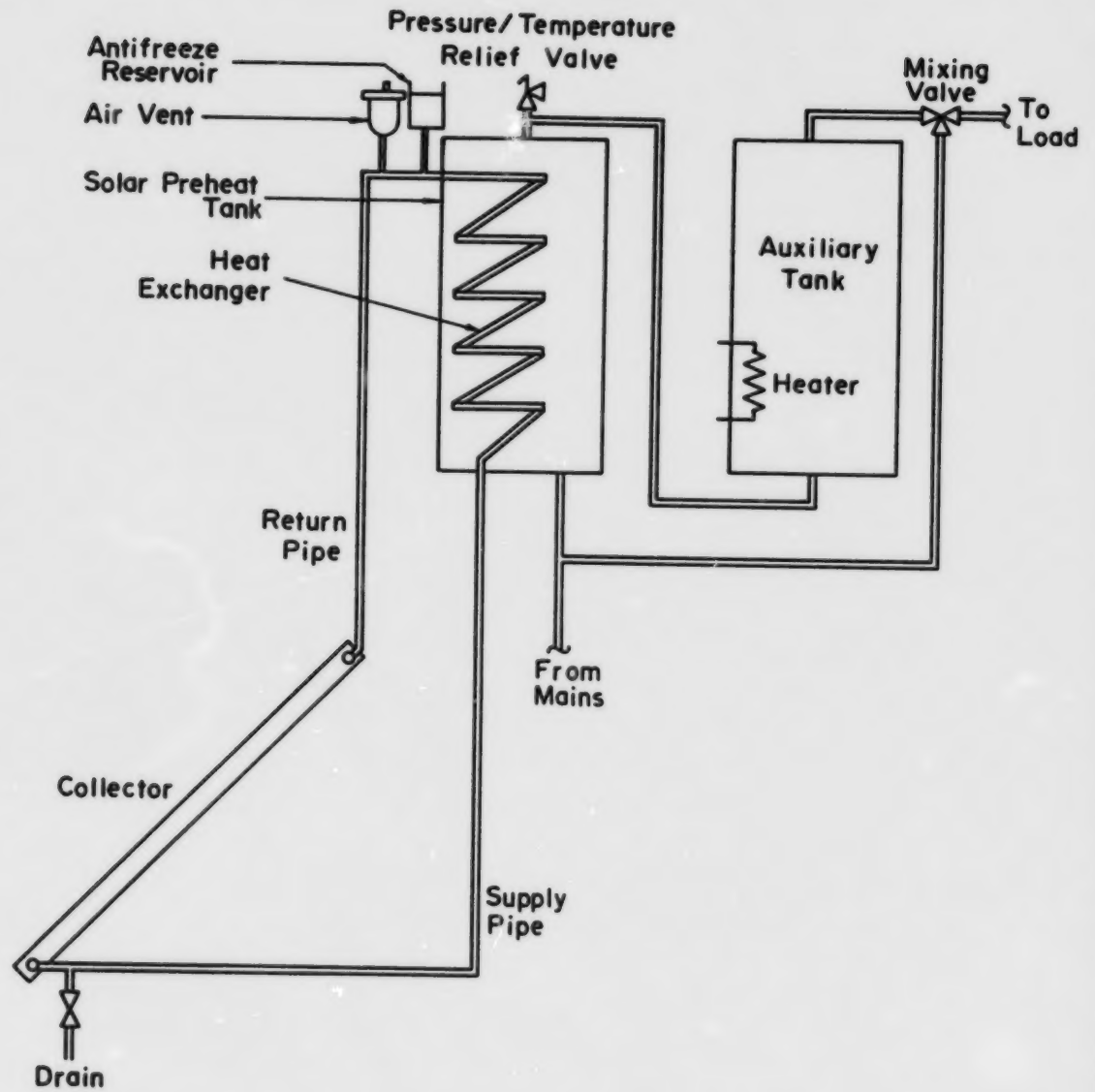


Figure 3.9 Typical Antifreeze Thermosyphon System

Other SDHW Systems

There are many other types of solar domestic hot water systems including draindown, pressurized drainback, and freon-based systems. In draindown systems, no heat exchanger or antifreeze is used. During heat collection, the collectors and tank are filled with water at city mains pressure. When there is a danger of freezing, two electrically controlled valves, one in the collector supply line and one in the collector return line, close. A third valve opens, draining all water in the collector and collector lines up to the two closed valves into a floor drain. The principal advantage of this system is that no heat exchanger is needed. The reliability of freeze-protection, especially in cold climates, has not been proven for these systems. At present, draindown systems are not used in the Canadian climate.

A similar system to the draindown system is the pressurized drainback system. This system also requires no heat exchanger. An air compressor maintains a pocket of air in the top of the pre-heat tank. When the pump shuts off, the compressed air rises to the collectors, displacing the water. Thus, during freezing conditions, the collectors are filled with air at city mains pressure.

A variation of the antifreeze SDHW system is the recently developed freon-based system. Freon (typically R114) is used in the collector loop instead of glycol. The solar heat gain is stored as latent heat in the freon: as freon is pumped through the collector, it changes from a liquid to a gas, and the freon condenses back to a liquid when it transfers its heat to the water in the storage tank. If the temperature (and therefore pressure) becomes too great, a pressure limiter closes, preventing freon from reaching the collector. The advantages of freon are constant temperature across the collector (therefore lower collector heat loss) and, because of a low flow rate, lower pumping power. The main disadvantage of these systems is the higher standard of quality required in the pipe and collector connections (freon vapour at a high pressure could leak, where water or glycol could not).

A variation on the freon system described above is a freon-based thermosyphon system. This system is similar to the antifreeze thermosyphon system, except that freon is used instead of glycol. In this system, freon is vapourized in the collector. The pressurized vapour rises to the tank where it condenses and transfers its heat to the water. The condensate returns by gravity to the bottom of the collector. Because of the low density of freon vapour, the collector return pipe must be oversized and kept as short as possible, in order not to restrict the flow.

3.2.2 Performance and Reliability

Many studies have been done on the performance and reliability of solar DHW systems. Ontario Hydro monitored the performance of systems under controlled conditions at their research lab between 1979 and 1982 [10,11,12]. The National Research Council maintained a test trailer with eight SDHW systems between 1982 and 1984 [13,14]. Several monitoring projects have looked at the performance of SDHW installed on homes. The two most recent projects were a study by TES Ltd. on the performance between 1983 and 1985 of SDHW systems [15] and another by Buchan, Lawton and Parent Ltd., (BLP) of 129 systems between 1984 and 1986 [16].

Although the Ontario Hydro studies are dated, they provide interesting information on system reliability. In the first year of testing (1979) the four systems were operational for only 55% of the time. System reliability problems included faulty controls, broken glazings, and pump failures. By 1981, the reliability of the six systems tested had increased to 99.8%. The average system efficiency (solar energy delivered divided by solar energy incident on the collectors) was 26%, with an annual solar contribution of 1.3 GJ per square metre of collector. Analysis of the National Research Council monitored data showed that average system efficiency had increased to almost 30%, or 1.5 GJ/m². It was concluded that the better systems would deliver approximately 1.8 GJ per square metre.

The Ontario Hydro and NRC studies were done under controlled conditions with a constant daily water load; the TES and BLP monitoring studies, done on actual installations, showed that the solar contribution varied significantly from site to site. The main reason for the variation was the magnitude of the water load. On average, the systems delivered 1.1 to 1.2 GJ annually per square metre of collector area. Households with small water loads, however, were getting 0.5 GJ/m², whereas large water users were getting over 2.0 GJ/m² with the same system type.

In comparing the performance of the different system types, drainback systems generally perform better than antifreeze systems. The BLP study showed that on average drainback systems delivered 30% more solar energy than antifreeze systems (1.3 GJ/m², compared to 1.0 GJ/m²). The NRC study also showed that most drainback systems out-performed antifreeze systems. The best system in that study however, was an antifreeze thermosyphon system. This system delivered approximately 2 GJ/m², 15% higher than the performance of the best pumped system. The only other Canadian thermosyphon system that has been monitored also showed high performance. A water-based system at Chutes Provincial Park delivered 0.95 GJ/m² over a five-month summer period [17]. Extrapolating performance to a full year would give an annual performance of 1.9 GJ/m². SDHW system performance is capable of being improved to 1.8 to 2.0 GJ/m², if the size of system is chosen to more closely match the water load. With an average system size of six to seven square metres, appropriately sized systems should save approximately 11 GJ per year. For households with small water loads, a small (or no) system should be installed. The oversizing problem may be partly related to the Energy, Mines and Resources subsidy levels: the larger the system, the larger the subsidy.

Reliability of SDHW systems appears to have improved significantly in the last few years. In the TES and BLP studies, reliability was a minor problem, with approximately 10% of the systems having failures that shut the system down for an extended period of time. The BLP experience was that collectors were relatively trouble-free: the most commonly reported problems were pump failures, control problems, and storage tank

leakage. Almost all of the storage tank problems, however, were limited to one manufacturer's product, which is no longer produced. In their study, piping did not show up as a problem area: it should be noted, however, that only obvious faults were reported to BLP, and minor problems (such as improperly installed piping or pipe insulation) would not have been reported.

The U.S. experience with solar DHW system reliability has not been as good. Because of the warmer climate, there has been greater use of draindown and heat-tracing as the means of freeze protection. In a review of reliability studies [18] it was concluded that these systems had six times more problems than drainback or antifreeze systems. The most recent (1982) reliability study reviewed showed that 30% of the systems had problems. The major problems encountered in the U.S. systems were piping leaks, controller failure, collector leaks and broken glazings. In a follow-up study [19], it was concluded that system design and reliability had improved significantly since the earlier studies. However, design, installation and operation problems still existed. Major problem areas were controller/temperature sensor failure and freeze protecting draindown systems.

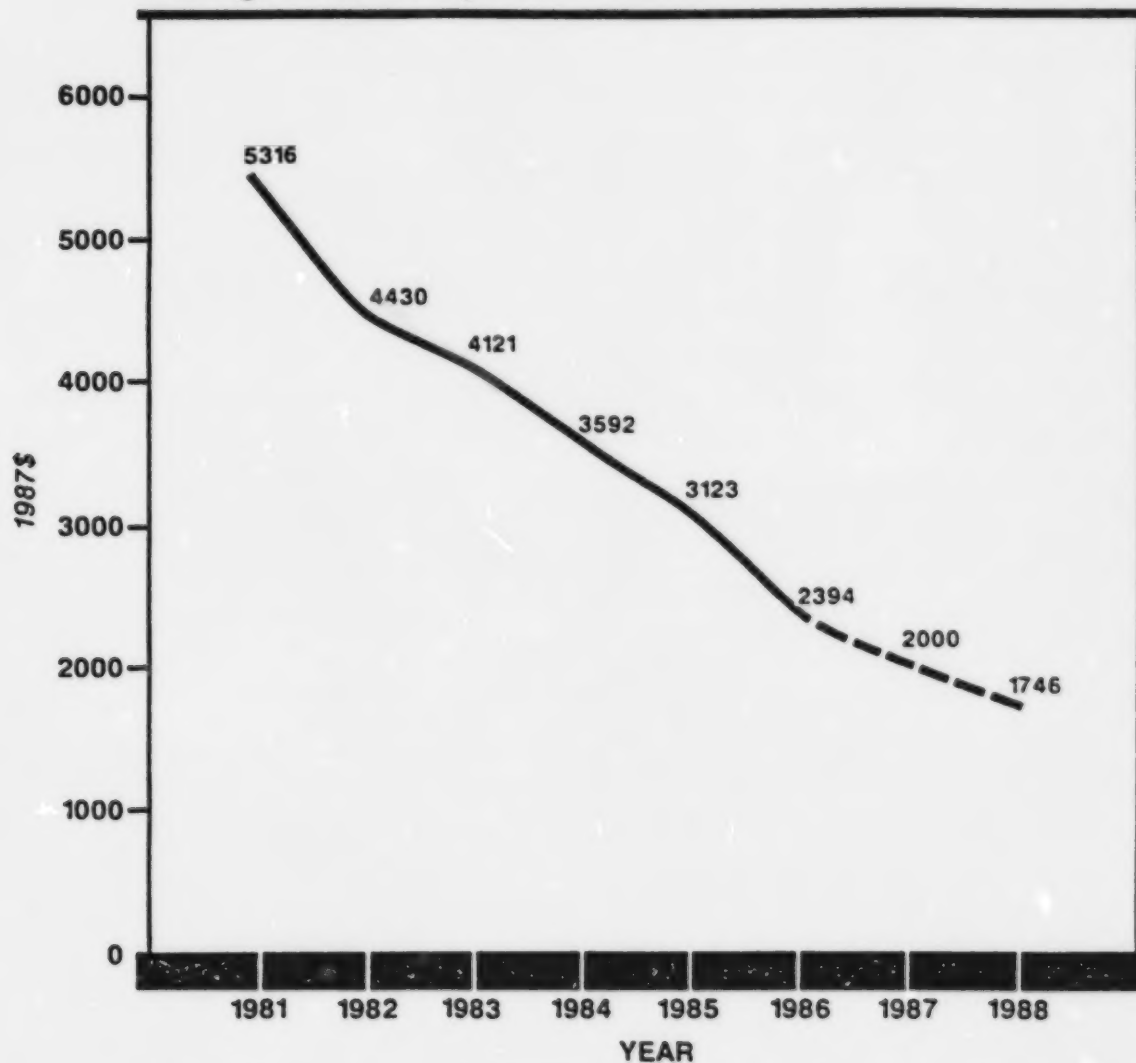
3.2.3 Economics and Market

The cost of solar DHW systems has consistently been decreasing. Figure 3.10 shows the average installed cost of SDHW systems installed under the EMR solar demonstration program [2,20]. The projection for 1987 is that the average installed cost will drop to \$2000 with a government subsidy of \$900. The EMR subsidy program is to end March, 1988. The actual 1988 installed cost may be significantly different since subsidy programs tend to distort the market place.

Cost performance of solar heating systems is often quoted in terms of dollars per annual gigajoule, as determined by dividing the total installed cost by the first year's savings (in GJ). The simple payback on the investment can be calculated by dividing the cost performance by the local fuel cost (including fuel conversion efficiency). In Ontario,

DHW Systems

Average Costs (\$/System)



February 1987

Figure 3.10 Average Installed Cost of Solar DHW Systems in 1987 Dollars (From Reference 2)

the incremental price of residential electricity is approximately 5¢/kWhr, or \$14/GJ, and for natural gas is 21¢/m³, or \$8.70/GJ (assuming 65% seasonal combustion efficiency). The cost performance of appropriately sized SDHW systems without any subsidy is approximately \$200 per annual GJ (see Figure 3.11). The simple payback on this investment would be 14 to 23 years, depending on the fuel displaced. It has been suggested that the cost performance would have to be reduced to \$100 per annual GJ to penetrate the Ontario market [3].

A typical breakdown of SDHW system costs by component is shown in Figure 3.12 [2]. While these percentages will vary from manufacturer to manufacturer, the important point is that no single component represents more than 30% of total cost. To significantly reduce system costs will require cost reductions in all components.

The market for SDHW systems has increased steadily over the past 8 years (see Figure 1.1) [1]. Thirty-four percent of the systems sold have been installed in Ontario. The jump in market size from 1980 to 1981 was caused by the introduction of the EMR solar demonstration program. In the past three years, annual sales has levelled out at approximately 19000 square metres (approximately 3000 systems). As all the subsidy funds were not used up, it can be concluded that, at present market awareness and a net cost to the homeowner of \$1400, the annual Canadian market for SDHW systems is approximately 3000 systems. When the EMR subsidy program is discontinued after March 1988, it would appear that SDHW system sales will decrease significantly.

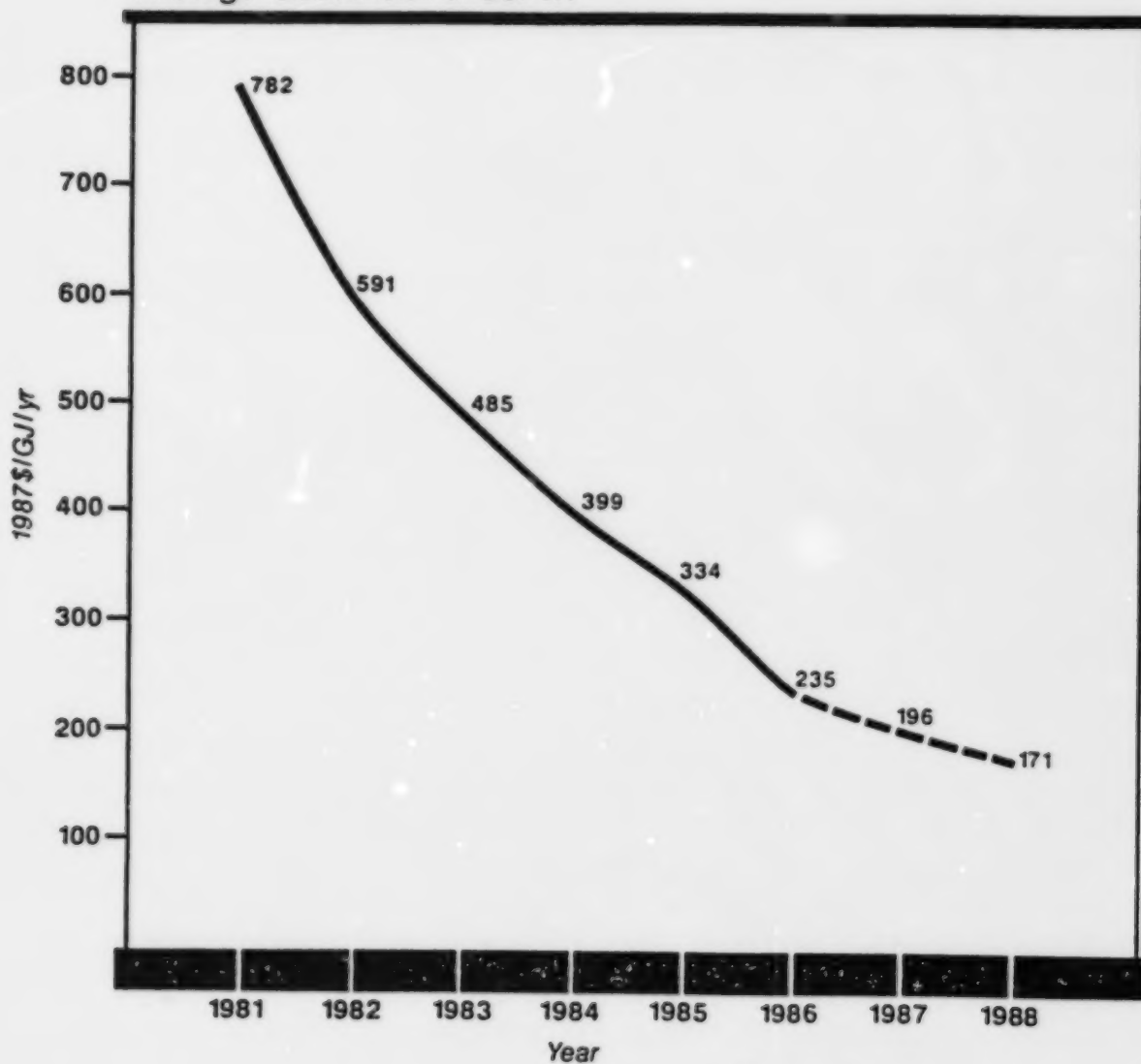
3.3 Active Solar Space Heating Systems

3.3.1 System Descriptions

There are two basic types of active solar space heating systems: air-based and liquid-based. Both of these systems can be easily incorporated into forced-air space heating systems. However, neither of these systems is compatible with hot water radiator heating systems.

DHW Systems

Average Costs(1987\$/GJ/Yr)



February 1987

Note: 1986 figure includes systems from both Phases VI and VII

Figure 3.11 The Cost Performance of Solar DHW Systems
(From Reference 2)

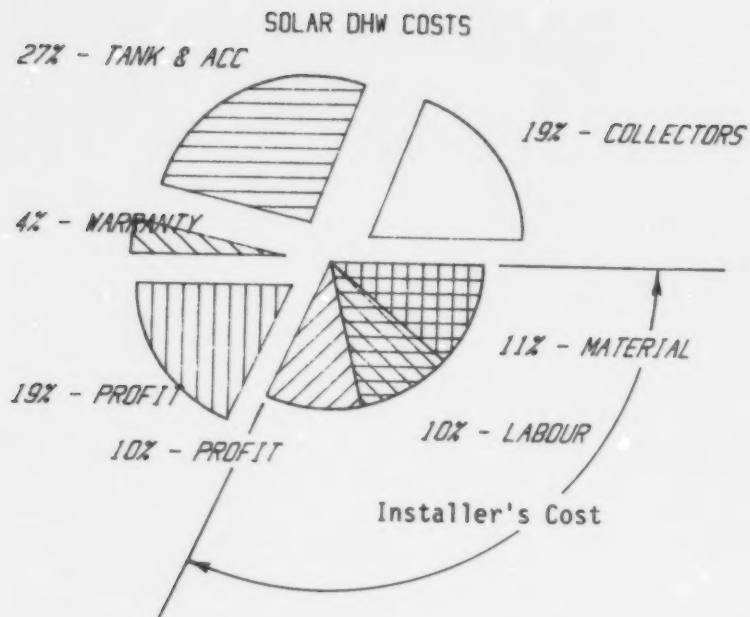


Figure 3.12 Solar DHW Cost Breakdown

The high radiator temperature necessitates high collector outlet temperature usually beyond the range of efficient operation. Therefore, the two types of solar heating system will be discussed only in conjunction with forced-air heating systems.

Liquid-based Solar Space Heating Systems

Figure 3.13 shows a typical liquid-based solar space heating system. The system consists of two sections: solar heat collection and solar heat delivery. The solar heat collection section is similar to that used in solar domestic hot water systems. The heat collection method can be either antifreeze or drainback (see Section 3.2.1). Drainback systems (as shown in Figure 3.3) require no heat exchanger. When there is a positive temperature difference between the collector and the storage tank, the pump circulates water through the collectors. When the sun goes down, the pump shuts off and the water drains back into the tank. Antifreeze systems use glycol as the collector fluid, and require a heat exchanger to keep the glycol separate from the water (see Figure 3.5). The advantages and disadvantages of the two heat collection methods were discussed in Section 3.2.1.

The solar storage tank for space heating systems is much larger than that used in solar domestic hot water systems. A typical residential storage tank would contain over 2000 litres of water. Because city water pressure is not needed to push water through the tank, the storage tank is usually unpressurized. As discussed in Section 2.3.2, solar heating systems could use extremely large tanks for seasonal storage of solar heat. These systems have had problems with high thermal losses from storage, tank water leakage and poor performance (see Section 3.3.2).

The solar heat delivery section is quite simple. An additional thermostat is placed in the house, set at the desired space temperature to control delivery of solar heat. The thermostat controlling the backup system is set one or two Celcius degrees below the first thermostat. As the temperature of the house drops, the solar thermostat will trip

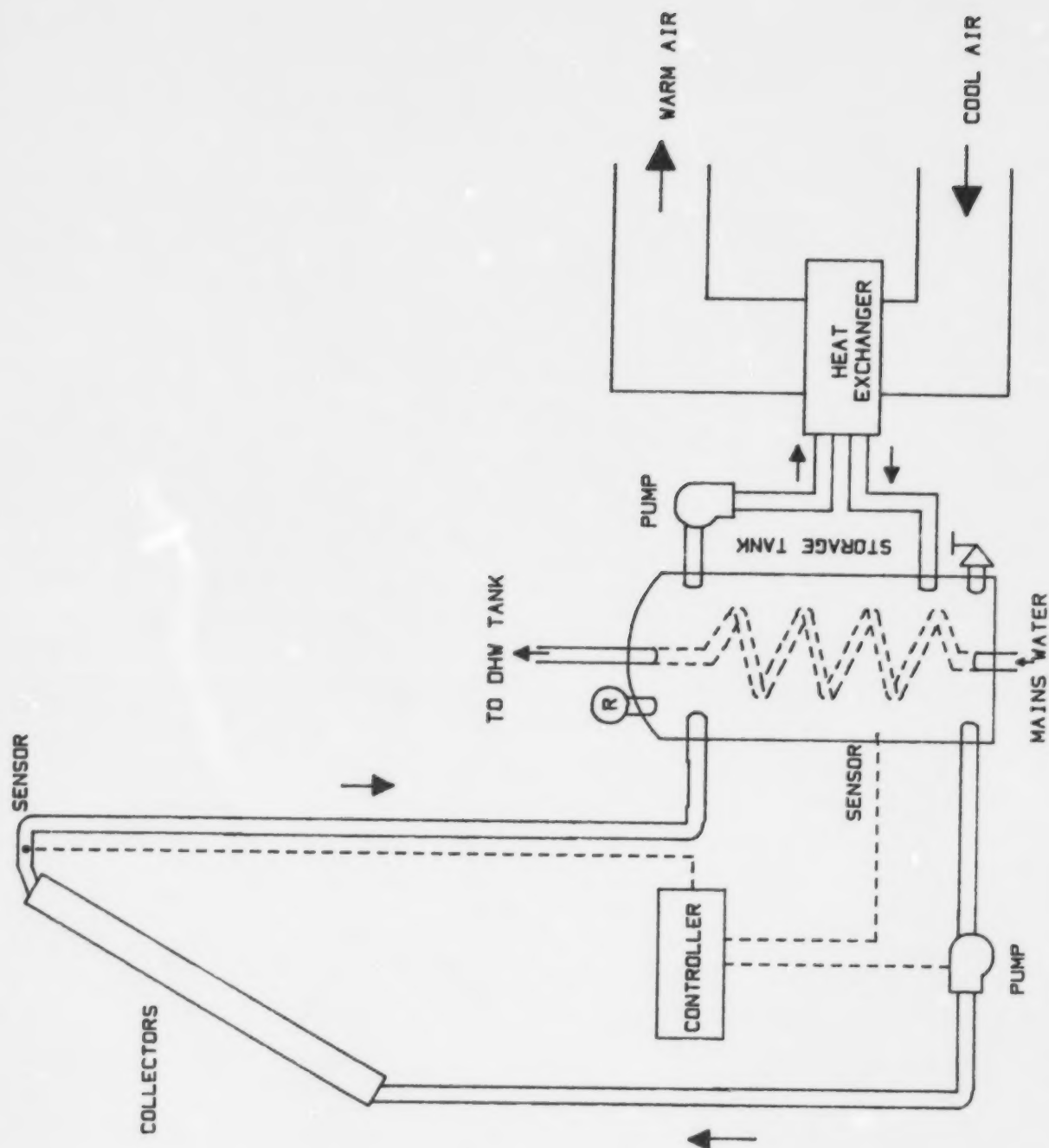


Figure 3.13 Typical Liquid-Based Solar Space Heating System Schematic

first. If the temperature sensor in the storage tank is above the room temperature, the heat delivery pump and furnace fan will come on. Hot water from the solar storage tank is circulated through the water-to-air heat exchanger, transferring heat to the building air. If the solar heat cannot prevent the building temperature from falling further, the backup thermostat would trip and the furnace would come on.

In order to utilize some of the summer solar radiation, space heating systems usually include a domestic hot water pre-heating option. The simplest method of heating city mains water is to install a immersed coil heat exchanger in the storage tank as shown in Figure 3.13. City mains water would flow through this heat exchanger before entering the conventional water tank.

Air-based Solar Space Heating Systems

Figure 3.14 shows a typical air-based solar space heating system. In this system there is no circulation of water: all solar heat is transferred by air movement. The system has three modes of operation: 1) storing solar heat, 2) heating building from collectors, and 3) heating building from storage.

If the building does not require heat and the collector temperature is greater than the storage temperature, the system will operate in the first mode (storing solar heat): the collector fan circulates air from the collectors through the rock bed storage unit, and the building fan motorized damper should be closed to prevent air entering the building.

If the building requires heat and the sun is shining, the second mode (heating building from collectors) will operate: the collector and building fans pulls air from the collectors and blows it into the building. No air circulates through the storage unit in this mode.

If the sun goes down and the building still requires heat, the third mode (heating building from storage) will operate: the building fan pulls air from the building through the storage unit and back to the

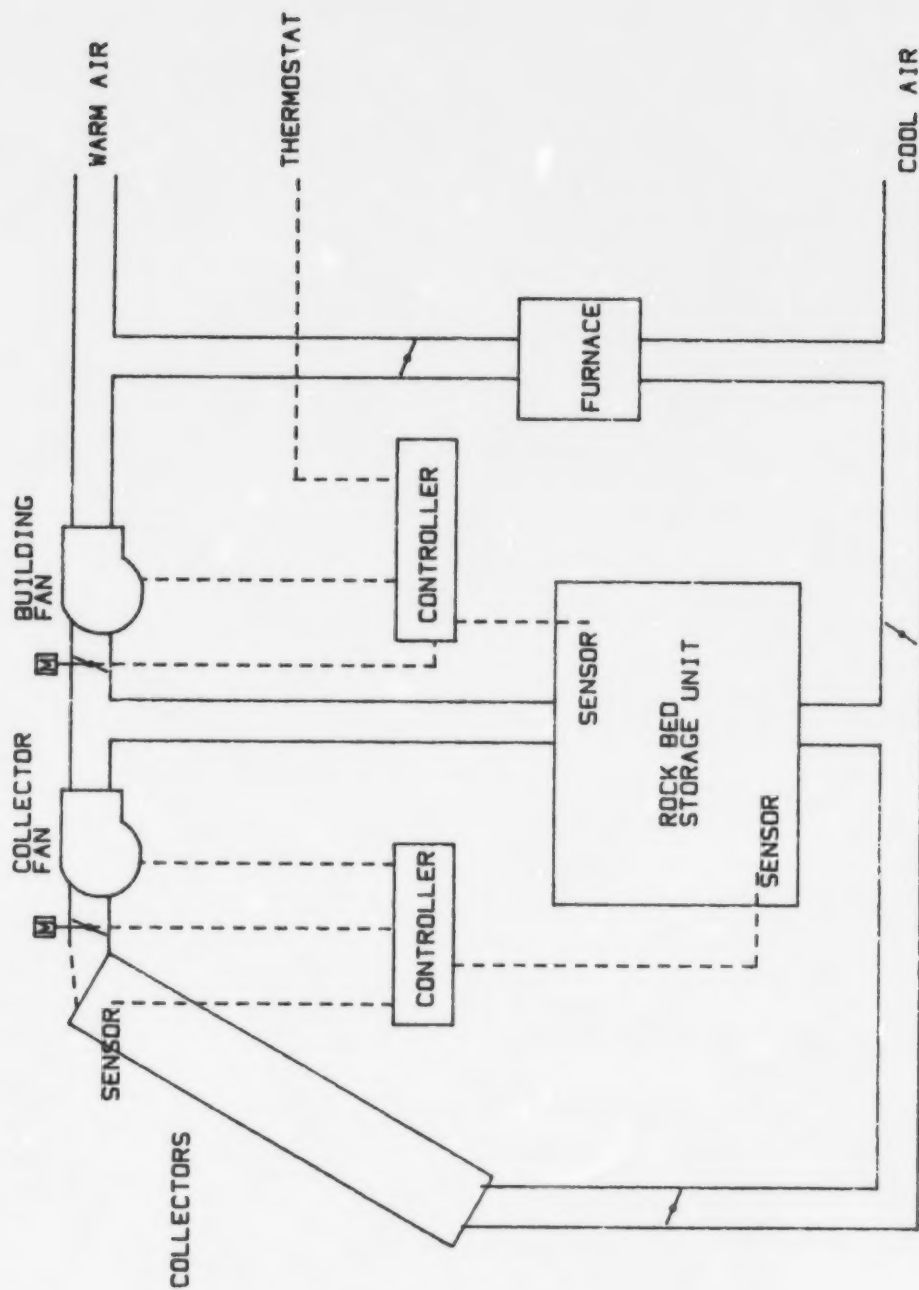


Figure 3.14 Typical Air-Based Solar Space Heating System Schematic

building, and the collector fan motorized damper should be closed to prevent air from circulating through the collectors.

The forced-air furnace is normally placed in parallel with the solar heating system so that, if the solar heating system cannot meet the heating demand, the furnace will come on.

Because of thermal stratification in rock bed storage units (see Section 2.3.3), it is necessary to use two temperature sensors in the unit: the sensor at the bottom of the rock bed controls the amount of heat that can be stored in the unit, and the sensor at the top controls the amount of heat that can be removed from the unit.

Solar heat delivery to the building is controlled in the same manner as liquid-based systems. An additional thermostat is installed in the house, set one or two degrees above the thermostat controlling the furnace. The solar thermostat will switch on first, and the furnace comes on only if the solar system cannot meet the heating load.

Air-based solar heating systems can also be used to pre-heat domestic hot water. To accomplish this, an air-to-water heat exchanger is installed just after the collector fan. Backdraft or motorized dampers must be used to prevent freezing on cold winter nights. When solar heat is available, a pump circulates water from a pre-heat tank to the heat exchanger. Thus, during the summer months, the system would operate only in the collector-to-storage mode.

A zero-storage solar space heating system is a variation of the air-based system described above. In this system there is only one mode of operation (mode 1 of Figure 3.14), and no storage unit is used. The advantage of these systems is that the cost of the storage unit and associated ductwork and controls is eliminated. This type of system is best suited to buildings that can accommodate large temperature swings, such as warehouses or thermally heavy buildings or houses. The solar contribution should be kept low (under about 35% of the load), so that the system is not oversized on sunny days.

3.3.2 Performance and Reliability

Very few solar space heating systems have been installed or monitored. The poor system performance is attributable to the mismatch between solar availability and heating demand. Simulation studies have shown that systems should deliver about 1 GJ/m² per year [3]. The performance of the solar space heating system at Aylmer Senior Citizens' Home was monitored; however, even by using seasonal storage of solar heat, the annual performance was only 1.2 GJ/m² [21].

The main reliability problem with air-based solar space heating systems has been air leakage: the large number of collector and duct joints results in much of the solar heated air leaking out before reaching the storage box or the space. The seasonal storage systems installed in Canada have had problems with water leakage, as movement of the earth and the thermal expansion/contraction of tank walls make it difficult to maintain tank integrity.

3.3.3 Economics and Market

The cost of a typical residential solar space heating system is in the \$10,000 to \$20,000 range. For new construction equal or better energy savings can be achieved through energy efficient design at a cost of approximately \$6,000. As a result, there are almost no residential solar space heating systems being installed in Canada. Two air-based collector manufacturers are actively selling a zero-storage space heating system for warehouses and industrial buildings. The performance of this type of system is discussed further in Section 3.4.

3.4 Commercial/Industrial/Institutional Solar Heating Systems

3.4.1 System Descriptions

Low Temperature Process Water Heating

One of the most promising applications for solar energy is heating of low temperature process water. The low water temperature, large volumes of water, and consistency of use ensure high utilization of solar energy.

Many industrial processes require large volumes of low temperature (below 65°C) water: major consumers include food processors, bottlers, breweries, fish hatcheries, film processors, and laundries.

Most process water heating systems, although much larger, are similar in layout to the solar domestic hot water systems described in Section 3.2.1. The large size of industrial solar heating systems often results in lower installation costs. One of the largest solar heating systems in Canada (consisting of over 2000 square metres of collector area) is used for heating water in an industrial laundry (see Figure 3.15).

The large size of industrial systems means that most are custom-designed. If the industrial process uses water constantly during daylight hours for almost every day of the year, then a thermal storage unit may not be necessary: in these cases, a solar heating system can be installed at a much lower cost.

Ventilation or Process Air Preheating

In many buildings a high rate of ventilation air change is necessary for the health of occupants or for proper operation of equipment. Such buildings include hospitals, vehicle maintenance garages, indoor swimming pools, gymnasias, and commercial kitchens. Many industrial processes require large volumes of air including paint drying, food drying, and sterilization/drying of bottles and cans. Large quantities of energy are required to raise the air temperature to the building or process temperature.

Air-based solar collectors can preheat ventilation or process air efficiently and at relatively low cost. Figure 3.16 shows a typical solar preheated ventilation air system. The system differs from conventional air-based solar heating systems in two important areas. First, the inlet air to the collectors is the outside air, as opposed to the building air; this means that the collector will operate at a lower

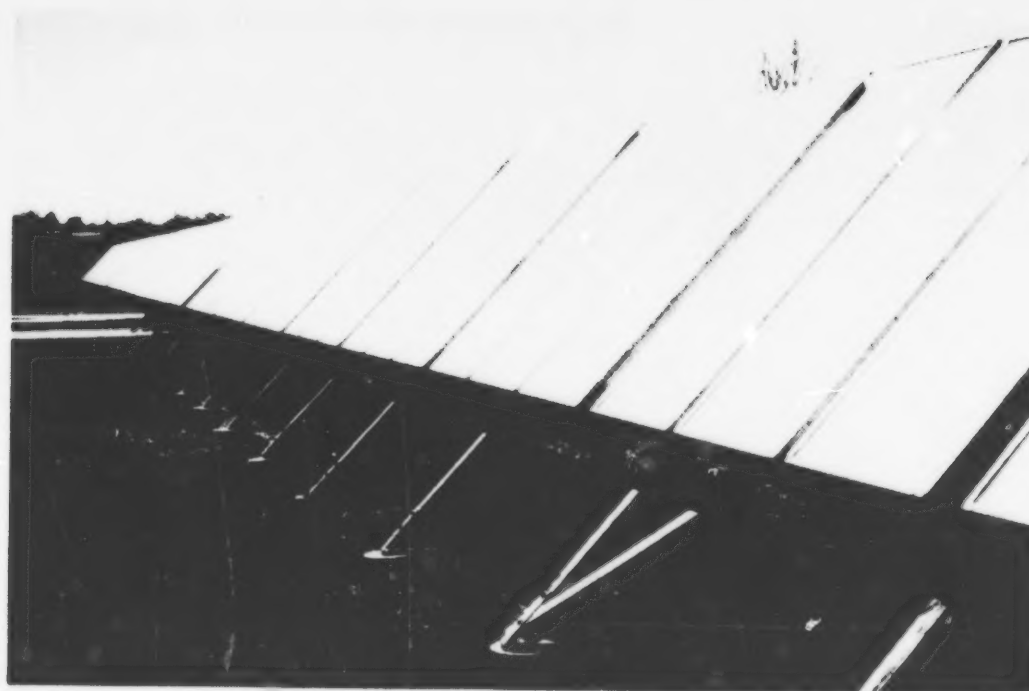
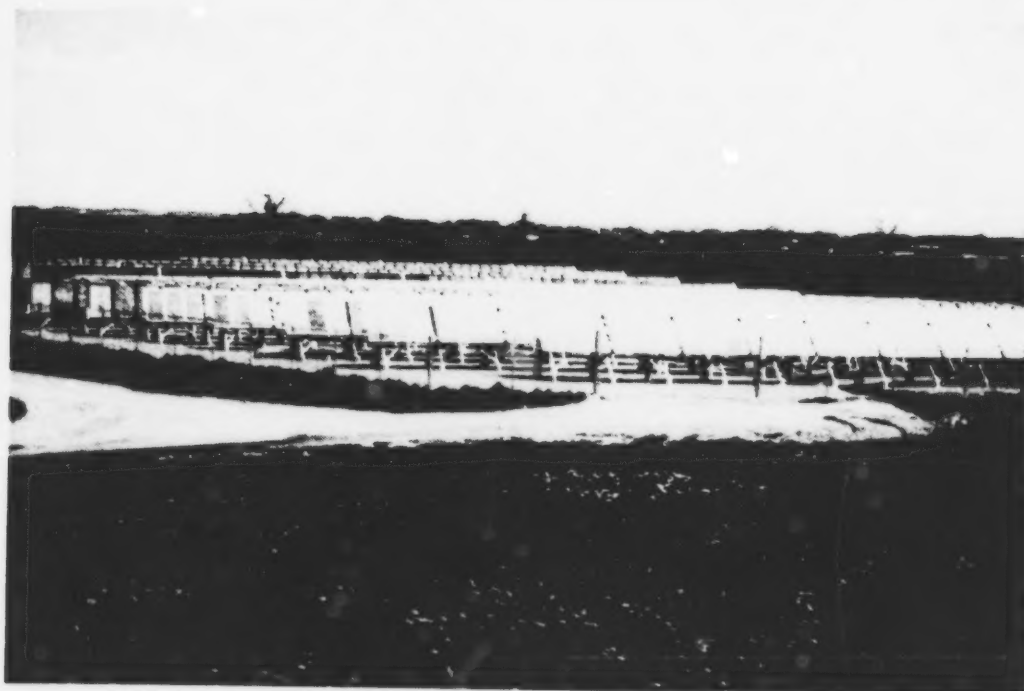


Figure 3.15 Largest C/I Solar Water Heating System in Ontario
- Mohawk Hospital Services, Hamilton

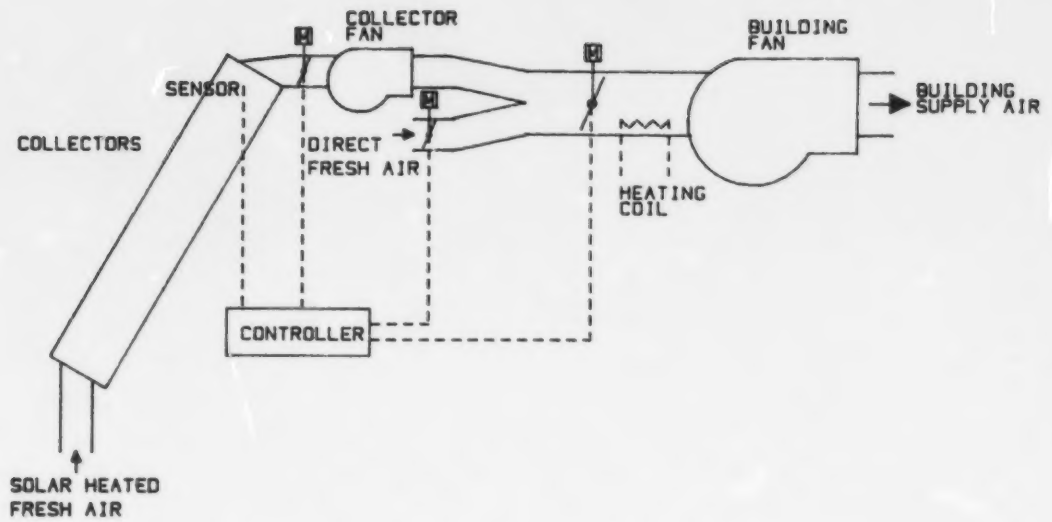


Figure 3.16 Typical Solar Preheated Ventilation Air System

temperature and higher efficiency. In this system, a site-built collector can be used even though it may have some air leaking in with only a small loss in performance. Second, because solar energy is delivered immediately to the load, there is no need for thermal storage.

The system has three modes of operation: 1) partial solar heating, 2) full solar heating and 3) no solar heating. The first mode will operate during most of the winter. In this mode, all ventilation air is drawn through the collectors, and the conventional heating unit upgrades the temperature to the desired value. As the ambient temperature increases, less heating is required. A temperature will be reached where the solar collectors can supply more than enough heat to meet the heating load, and at this point, some of the air flow is diverted to the direct air intake (mode 2), such that the temperature of the combined air streams is equal to the desired temperature. If the outside temperature is greater than the desired temperature, no air flows through the collectors (mode 3).

3.4.2 Performance and Reliability

There have been two major programs for the installation of Commercial/Industrial/Institutional solar heating systems. The Ontario government program helped finance the installation of almost one hundred systems between 1982 and 1984. To date, the E.M.R. program has supported the installation of approximately 170 Commercial/Industrial/Institutional systems across Canada over 50 of which are in Ontario.

Under the Ontario program, all systems were monitored and data analysed: the complete results are contained in references 17, 22 and 23. A summary of the performance results for each project is shown in Table 3.1. Three performance numbers are shown for each project: solar delivered, solar delivered adjusted, and solar predicted. All numbers have been normalized to one year and to unit collector area. Solar delivered is the actual solar energy delivered to the load. Solar delivered adjusted is the actual solar energy delivered, plus an estimate of solar

BUILDING	TYPE	APPLICATION	COLLECT	ACTUAL	SOLAR	SOLAR
			AREA	SOLAR	DEL'D	PRED'D
			[M ²]	DEL'D	ADJUST	
				← [GJ/M ² /YR] →		
COMFORT LIVING CO-OP	DRAIN	DHW	214.0	1.92	1.92	1.83
BARRIE COMMUNITY CENTRE	DRAIN	DHW	89.2	1.31	1.31	1.54
QUEEN'S UNIVERSITY GYM	DRAIN	DHW	293.0	1.14	1.20	1.90
LITTLE'S NURSING HOME	DRAIN	DHW	135.0	0.93	0.93	1.32
MAPLEVIEW LODGE	DRAIN	DHW	29.7	1.70	1.70	1.56
COPPERFIELDS HOTEL	DRAIN	DHW	71.4	0.73	0.73	2.94
MUSKOKA SANDS INN	DRAIN	DHW	60.0	1.61	1.61	1.70
TRILLIUM REST.	DRAIN	DHW	29.8	0.15	0.53	
ALBION COMMUNITY CENTRE POOL	DRAIN	POOL	166.0	1.31	1.31	
CAMERON HEIGHTS POOL	DRAIN	POOL	250.0	1.44	1.46	1.54
CASSELL RESORT HOTEL	DRAIN	POOL	46.0	1.07	1.97	1.97
HURON PARK POOL	DRAIN	POOL	190.0	0.56	0.73	1.94
KINCARDINE COMMUNITY POOL	DRAIN	POOL	406.0	0.28	0.56	1.05
LINDSAY AQUATORIUM	DRAIN	POOL	119.0	1.24	1.79	1.74
MUSKOKA SANDS INN POOL	DRAIN	POOL	54.0	0.30	0.74	1.96
REGENCY FACILETS POOL	DRAIN	POOL	360.0	0.99	1.13	1.85
MS JOHNSON POOL	DRAIN	POOL	315.0	0.24	0.52	1.61
BARRYMORE CARPET COMPANY	DRAIN	PROCESS	332.0	0.75	0.75	3.22
CHRISTIE BROWN AND COMPANY	DRAIN	PROCESS	360.0	0.59	2.75	2.35
HOLIDAY JUICE COMPANY	DRAIN	PROCESS	324.0	1.01	1.31	1.29
MAEDEL BEVERAGE COMPANY	DRAIN	PROCESS	372.0	0.33	0.34	2.40
MEDALLION FILM LABS	DRAIN	PROCESS	336.0	1.40	1.40	1.47
PORRITTS & SPENDER COMPANY	DRAIN	PROCESS	649.0	0.18	0.21	1.05
RP. SCHERER COMPANY	DRAIN	PROCESS	495.0	1.42	1.52	1.91
HURON STEEL COMPANY	DRAIN	PROCESS	38.0	0.93	0.93	1.33
COUNTRY CLEAN CAR WASH	DRAIN	PROCESS	45.0	1.41	1.41	1.72
DELUZIO AUTO SERVICE	DRAIN	PROCESS	118.9	0.70	1.05	1.17
HANDOVER CAR WASH	DRAIN	PROCESS	107.0	0.29	0.60	0.54
MAVIS ROAD CAR WASH	DRAIN	PROCESS	108.0	1.53	1.53	2.26
COUNTRY CLEAN LAUNDRY	DRAIN	PROCESS	83.0	1.98	1.98	1.90
KINGSTON HOSPITAL LAUNDRY	DRAIN	PROCESS	271.3	1.47	2.01	2.27
QUICK CLEAN LAUNDRY	DRAIN	PROCESS	47.7	1.88	1.88	1.95
AYLMER SENIOR CITIZENS APTS	DRAIN	SPACE/DHW	218.6	0.17	0.81	1.24
AVERAGE=				0.87	1.17	1.75
TOTAL=			6733.5			

Table 3.1 Performance of Liquid-Based Solar Systems Installed
under the Ontario C/I Solar Demonstration Program

	TYPE	APPLICATION	COLLECT	ACTUAL	SOLAR	SOLAR
			AREA	SOLAR	DEL'D	PRED'D
			[M ²]	DEL'D	ADJUST	
				← [GJ/M ² /YR] →		
CENTRALIA COLLEGE	GLYCOL	DHW	132.0	0.25	0.27	0.39
CONFEDERATION COLLEGE	GLYCOL	DHW	100.0	0.09	0.21	1.00
225 MORNINGSIDE DR APTS	GLYCOL	DHW	125.0	2.09	2.09	1.64
PRINCE WILLIAM APTS	GLYCOL	DHW	233.0	0.11	0.38	0.84
YORK CONDOMINIUMS	GLYCOL	DHW	310.0	1.79	1.99	1.55
BETHESDA NURSING HOME	GLYCOL	DHW	59.8	1.18	1.49	1.11
ERIN MILLS SENIORS' LODGE	GLYCOL	DHW	150.0	1.12	1.12	1.61
PETERMANA SENIORS' HOME	GLYCOL	DHW	24.0	1.31	1.35	2.07
SARSFIELD SENIORS' HOUSING	GLYCOL	DHW	46.0	0.37	0.62	1.42
SHEFFIELD SENIORS' HOME	GLYCOL	DHW	40.0	1.08	1.08	1.22
ST. ANDREW'S SENIORS' PLACE	GLYCOL	DHW	150.0	0.63	1.05	1.38
CORAL MOTEL	GLYCOL	DHW	47.8	0.99	0.99	1.29
RENAISSANCE HOTEL	GLYCOL	DHW	288.0	2.02	2.02	1.91
PROVINCIAL GOV'T OFFICES	GLYCOL	DHW	114.0	0.92	0.98	1.11
GUELPH CORRECTIONAL CENTRE	GLYCOL	DHW	238.0	2.26	2.26	1.54
KELSEY'S RESTAURANT	GLYCOL	DHW	129.0	1.02	1.02	1.19
HURONIA DRIFTWOOD RESTAURANT	GLYCOL	DHW/POOL	86.0	0.81	0.81	0.90
PETERBOROUGH FIREHALL	GLYCOL	DHW/SPACE	116.0	0.55	0.55	0.94
ST ELIZABETH SOCIETY POOL	GLYCOL	POOL	65.8	1.06	1.31	1.78
BARRIE YMCA	GLYCOL	POOL/DHW	98.0	0.87	0.87	1.31
DRYDEN ACTIVITY COMPLEX POOL	GLYCOL	POOL/DHW	200.0	1.54	1.61	1.68
CAMPBELL SOUP COMPANY	GLYCOL	PROCESS	586.0	1.13	1.13	2.22
ED SMITH AND SONS COMPANY	GLYCOL	PROCESS	846.0	1.90	2.18	
YORK ELECTROPLATING COMPANY	GLYCOL	PROCESS	59.0	0.56	0.56	0.69
MINUTE CAR WASH	GLYCOL	PROCESS	186.0	1.31	1.31	1.10
ANGUS LAUNDRY	GLYCOL	PROCESS	41.0	0.57	1.46	2.33
MOHAWK LAUNDRY	GLYCOL	PROCESS	2011.9	1.56	1.67	3.08
APPLEWOOD PUBLIC SCHOOL	GLYCOL	SPACE/DHW	230.0	0.87	0.92	1.57
NEWMARKET COURTHOUSE	GLYCOL	SPACE/DHW	186.0	0.30	0.30	
AVERAGE=				1.34	1.46	2.03
TOTAL=			6898.3			

Table 3.1 cont'd

energy that would have been delivered for any months when the system was not operable. Solar predicted is a computer estimated value using f-Chart and average weather data of what the system should deliver, based on the measured (i.e., actual) heating load. It should be noted that in many cases, the original designer's estimate of the load was much greater than the subsequent monitored load. In general, the difference between solar delivered and solar delivered adjusted can be thought of as lost performance due to design mistakes which caused the system to fail. This difference should decrease as designers become more familiar with solar system design. The difference between solar delivered adjusted and solar predicted is probably due to non-ideal system operation and system components operating below specification.

On average, the liquid-based systems delivered only 60% of the predicted solar contribution. When the systems were operating, they delivered 70% of what was expected. The average annual solar contribution was only 1.1 GJ/m², although there were several systems that delivered over 2.0 GJ/m². Glycol or antifreeze systems performed better than drainback systems, however, most of the difference can be attributed to the very large system at Mohawk Hospital Laundry. Other than reliability problems (discussed later), the main reasons for the poor performance include:

- system oversized for water load
- improper piping design (i.e., design does not ensure hottest tank water goes to load and/or coldest water goes to collectors)
- no check valve to prevent nighttime reverse thermosyphoning in collector loop
- poor heat exchanger performance
- inadequate insulation
- operator errors (often due to lack of operator's manual)
- high "threshold" power requirements for heat pipe collectors (see Section 2.1.6)

The Ontario program also sponsored the installation of eight air-based solar heating systems. The monitored performance of these systems is shown in Table 3.2. The air systems had a very poor average performance

			COLLECT AREA [M ²]	SOLAR DEL'D ACTUAL ← [GJ/M ² /YR] →	SOLAR DEL'D ADJUST	SOLAR PRED'D
			TYPE	APPLICATION		
INELIS CARPET CLEANERS CO	AIR	PROCESS	220.0	0.71	0.73	0.75
TRENT TIMBER TREATING CO	AIR	PROCESS	222.0	0.22	0.22	
ANCHOR CONCRETE PRODUCTS	AIR	PROCESS	161.0	0.30	0.30	
ALL SAINTS CHURCH	AIR	SPACE	259.0	0.16	0.15	1.30
CEDAR PARK CHURCH	AIR	SPACE	57.0	0.43	0.43	1.39
METRUS INDUSTRIAL PARK (ROOF)	AIR	SPACE	70.8	0.52	0.52	0.90
METRUS INDUSTRIAL PARK (WALL)	AIR	SPACE	51.5	0.33	0.33	0.90
ST. JAMES CHURCH	AIR	SPACE	80.0	0.12	0.12	0.85
			AVERAGE=	0.34	0.34	1.03
			TOTAL= 1121.3			

Table 3.2 Performance of Air-Based Solar Systems Installed
under the Ontario C/I Solar Demonstration Program

of less than 0.5 GJ/m^2 . The space heating systems suffered from collector air leakage and summertime shutdown. One of the process air systems had reasonable performance, whereas the other system had a low solar contribution because the process load was not continuous.

The performance of the 27 E.M.R. systems that have sufficient monitoring data are reported in Reference 24 and shown in Table 3.3. When operating, the systems had a significantly higher solar contribution (1.65 GJ/m^2) than the Ontario projects (1.3 GJ/m^2), but they still are delivering below their predicted potential. It would appear that the majority of the performance improvement is being achieved by better selection of solar applications, with minor improvements in design or operation. Two of the E.M.R. systems could have annual solar contributions of over 3 GJ/m^2 , if they were designed and operated properly.

Reliability in Commercial/Industrial/Institutional systems has been lower than with solar DHW systems. Systems installed under the Ontario and E.M.R. solar demonstration programs had a average of one reliability problem per system. Most reliability problems were minor and did not take long to repair: the average system operated more than 90% of the time. Table 3.4 gives ranking of the components experiencing the greatest number of problems. Major problems included collectors blown off a roof by wind, steam explosions in collectors, and freezing of water in collectors. A summary of the system problems and their remedies is given in Reference 25.

It would appear that reliability problems appear to be greatest with the components and design features unique to solar systems (i.e., solar collectors, solar controllers, and exterior piping). It is possible that many of these problems will be overcome as manufacturers, designers, and installers gain greater experience with solar heating systems.

		COLL AREA (M ²)	SOLAR DEL'D ACTUAL ←—————(GJ/M ² /YR)—————→	SOLAR DEL'D ADJUST	SOLAR PRED'D
TYPE	APPLICATION				
UPEI CTRAL UTIL BLDG	DHW	178.0	1.67	2.08	2.7
MANDEVILLE APT'S	DHW	45.5	1.05	1.31	1.9
23 BIRCH ST. APT'S	DHW	37.0	1.76	1.76	2.1
NELSON ST APT'S DRAINBACK	DHW	89.0	1.19	1.29	2.5
WETHERBY APT'S NORTH	DHW	52.8	1.89	1.89	2.4
WETHERBY APT'S SOUTH	DHW	70.4	1.25	1.25	2.4
DOGWOOD MANOR APT'S	DHW	33.0	1.54	1.54	2.5
MATHESEN HEIGHTS APT'S	DHW	40.0	0.96	1.61	2.8
NEST BAY APT'S	DHW	144.0	1.38	1.50	2.2
BURDETT APT'S	DHW	24.0	2.20	2.20	2.1
ESSEX NURSING HOME GLYCOL	DHW	135.0	2.38	2.38	2.3
LOBSTER SHANTY REST	DHW	39.0	2.26	2.26	2.1
LOBSTER TREAT REST	DHW	29.0	1.79	1.79	2.2
COVE MOTEL & REST	DHW	36.0	0.58	1.10	1.6
INN ON THE LAKE ML/RT	DHW	46.0	1.86	1.86	1.9
WANDLYN INN MOTEL/RES	DHW	120.0	1.14	1.14	2.2
BUTCHART GARDENS REST	DHW	45.0	1.74	2.50	2.4
U6FINEST ONT POOL GLYCOL	DHW	180.0	1.63	1.63	2.9
KEVIN'S CARMASH	PROCESS	54.0	1.19	1.25	2.7
BARREL LAUNDRY	PROCESS	24.0	1.70	1.70	2.4
CHEIFTAIN LAUNDROMAT	PROCESS	55.0	1.26	1.26	2.7
GOLD EYE CAR WASH	PROCESS	89.0	1.84	1.84	2.9
MITEI SEMICONDUCTOR DRAINBACK	PROCESS	150.0	1.07	1.83	3.1
CUSTOM WOOLEN MILLS	PROCESS	90.0	1.74	1.74	3.0
SUDBURY DOWNS POOL	POOL	90.0	1.11	1.61	2.7
OAK BAY REC POOL	POOL	318.0	0.24	0.77	2.5
ESQUIMALT REC POOL	POOL	108.0	0.89	1.47	2.7
AVERAGE=			1.46	1.65	2.4
TOTAL=		2321.7			

Table 3.3 Performance of Monitored Solar Systems under
the EMR C/I Demonstration Program

Table 3.4 Ranking of Components from Least to Most Reliable

1. Controllers and Sensors (31%)
 2. Collectors (24%)
 3. Piping (19%)
 4. Pumps (14%)
 5. Valves (7%)
 6. Heat Exchangers (3%)
 7. Storage (2%)
-

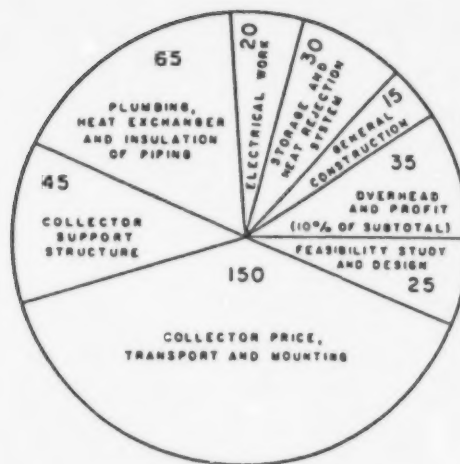
Commonly occurring problems included:

- controller or sensor malfunction
- liquid leaks in collectors, collector connections and piping
- pump failure
- glazing damage due to wind, snow or vandals
- improper installation of pipe insulation

3.4.3 Economics and Market

The cost of Commercial/Industrial/Institutional solar heating systems has decreased significantly in the last few years. The average system cost is approximately \$400 per square metre, although some systems (notably ventilation air preheat systems) have been installed for less than \$300/m² [26]. A typical system cost breakdown is shown in Figure 3.17 [3]. The collectors and their support structure represent over 50% of the system cost. A properly-sized and operated C/I/I solar heating system is capable of delivering 2 to 3 GJ/m²: therefore, the cost performance of these systems is in the range of \$130 to \$200 per annual GJ.

The cost performance of C/I/I solar systems has fallen dramatically since 1980 (see Figure 3.18). The figure also shows that the difference between predicted and actual performance is becoming less and less.



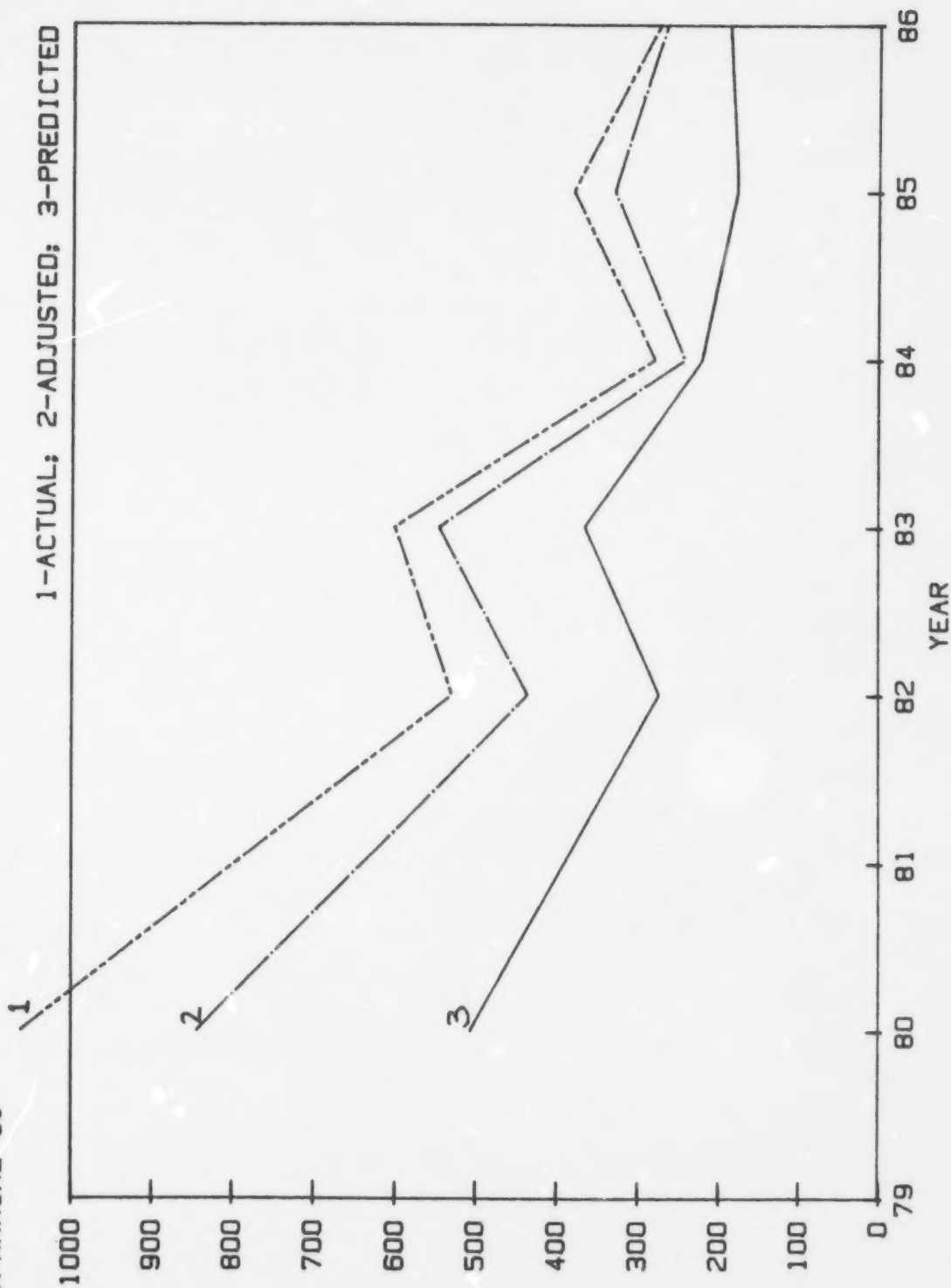
ALL FIGURES IN $\$/m^2$
TOTAL $\$385/m^2$

Figure 3.17 Cost Breakdown of a Typical C/I
Solar Heating System
(From Reference 3)

COST PERFORMANCE COM/IND SOLAR SYSTEMS

Figure 3.18

1987 \$/ANNUAL GJ



It has been suggested that, at current Ontario fuel prices, systems will have to be installed for under \$50 per annual GJ to achieve market penetration [3]. The non-solar energy savings of solar pre-heated ventilation systems (additional wall insulation and air de-stratification) often results in these systems being installed at less than the market threshold cost.

With government subsidies of approximately 50%, almost 300 Commercial/Industrial/Institutional (C/I/I) solar heating systems have been installed in Canada. The most common building types for solar installations have been apartment buildings and nursing homes, followed to a lesser extent by motels, restaurants, indoor swimming pools, and fish hatcheries. Many industries require large volumes of heated water; however, their owners are interested in projects that pay back in under only two years. Many of the building sectors that are using solar heating can be characterized as having a fixed revenue base, and can only increase profits by reducing costs (e.g., apartments and nursing homes).

Techniques for improving the cost performance of C/I/I solar systems are discussed in Reference 27. Without government subsidies, however, it would appear that Commercial/Industrial/Institutional solar installations would be limited to solar preheating of ventilation air and locations with very high fuel costs.

4. ASSESSMENT OF ACTIVE SOLAR INDUSTRY

4.1 Canadian Solar Manufacturers and Their Products

There are eleven Canadian companies (six of which are in Ontario) which manufacture approved products under the Canadian Solar Industries Association Products Acceptance Program:

<u>Manufacturer</u>	<u>Products</u>	<u>Notes</u>
Conserval Eng. Ltd. Downsview	Site built air collector	particulary suited for ventilation air preheating
Enersol Products Inc. Port Coquitlam, B.C.	Swimming pool collector	EPDM risers and ABS headers, unglazed
Fournelle Energie et Technologie Inc., Montreal	Evacuated tube collector	uses the Phillips tube
Norsun, Inc. Manotick	Liquid flat plate collector, SDHW system	uses a thermal diode collector
Solcan Limited London	Liquid flat plate collector, evacuated tube collector, drain back SDHW system	
Solway Energy Corp. Vancouver	Batch SDHW	particularly suited for mild climates
Sunglo Solar Limited Concord	Swimming pool collector	polypropylene absorber, unglazed
Sun Ray Solar Systems Windsor	Liquid flat plate collector, drainback SDHW system	
Sunstrip International Inc. Boucherville, Quebec	Liquid flat plate collector, swimming pool collector, drainback SDHW system	uses micro-flow collectors and system
ThermoDynamics Ltd. Dartmouth, N.S.	Liquid flat plate collector closed loop SDHW system	
Watershed Energy Systems Ltd. Toronto	Liquid flat plate collector, air-based collector	air collector is a site built "air bag"

The only two medium- or high-temperature products available in Canada are the evacuated collectors from Solcan and Fournelle. The high cost of these products has, however, restricted their sales. These are the only two medium- or high-temperature products available in Canada. There are two Ontario companies that have developed solar crop drying systems: Oboe Engineering Limited (Ottawa) and Abrico Energy Management Services Ltd. (Lakefield). A new company, Post Harvest Developments Inc., has just been formed to develop and market crop drying systems. Because these products are for the export market, the manufacturers have not sought CSIA product approval.

In summary, the products that are available are designed for low-temperature water heating and low-temperature air heating. For the liquid-based collectors, the heating loads could be swimming pools, domestic hot-water preheating, or heating of mains water for process loads. For the air-based collectors, the heating loads could be ventilation/process air preheating or low-temperature space heating.

4.2 Solar Technology Outside of Canada

Because of government assisted research, Ontario and Canadian solar products are on a world class level. There are, however, several products being developed in other parts of the world that could have significance for Ontario.

In Canada, solar collectors and DHW systems are custom assembled or short production runs. In Japan and Israel, water-based thermosyphon systems are mass-produced on fully-automated assembly lines at an annual rate of 50,000 units. The installed cost of these systems is approximately \$1500, significantly below the cost of Canadian systems. Although some reliable method of freeze-protection would be required for these systems in Canada, it nevertheless demonstrates the potential for cost reduction with mass production.

In Australia and Europe, considerable work is being done on evacuated tube collectors (ETC). Although still more expensive than flat plate collectors, they are more adaptable to mass production. It is possible that ETC could be produced at a cost significantly lower than flat plate collectors.

In Sweden, considerable work is being done on seasonal storage systems. Although the Canadian experience has not been positive, the Swedes have accomplished great improvements in cost reductions and reliability. Seasonal storage is appropriate to Canada because of the imbalance between summer and winter solar radiation intensities, and could be used to reduce peak loads on utilities.

4.3 Research and Support Facilities

There are four centres providing support services for the active solar industry: the Ontario Research Foundation, Institut National de la Recherche Scientifique, the University of Waterloo, and Queen's University. Financial support for these "Centres of Expertise" is provided by the Renewable Energy Branch of Energy, Mines and Resources Canada.

The Ontario Research Foundation operates the National Solar Test Facility (NSTF) at its offices in Mississauga. NSTF provides performance testing of air and liquid-based collectors and solar DHW systems to ASHRAE or CSA standards. A unique feature of the NSTF testing is that it is done indoors using an "artificial sun" (see Figure 4.1): a high intensity light source, developed by Vortek Industries of Vancouver, is focussed on the collector. The light source spectrum has been adjusted to closely match that of the sun and the intensity of the light source can be varied to allow testing at different solar irradiance levels. The use of the artificial sun allows continuous testing of systems without delays caused by cloudy weather.

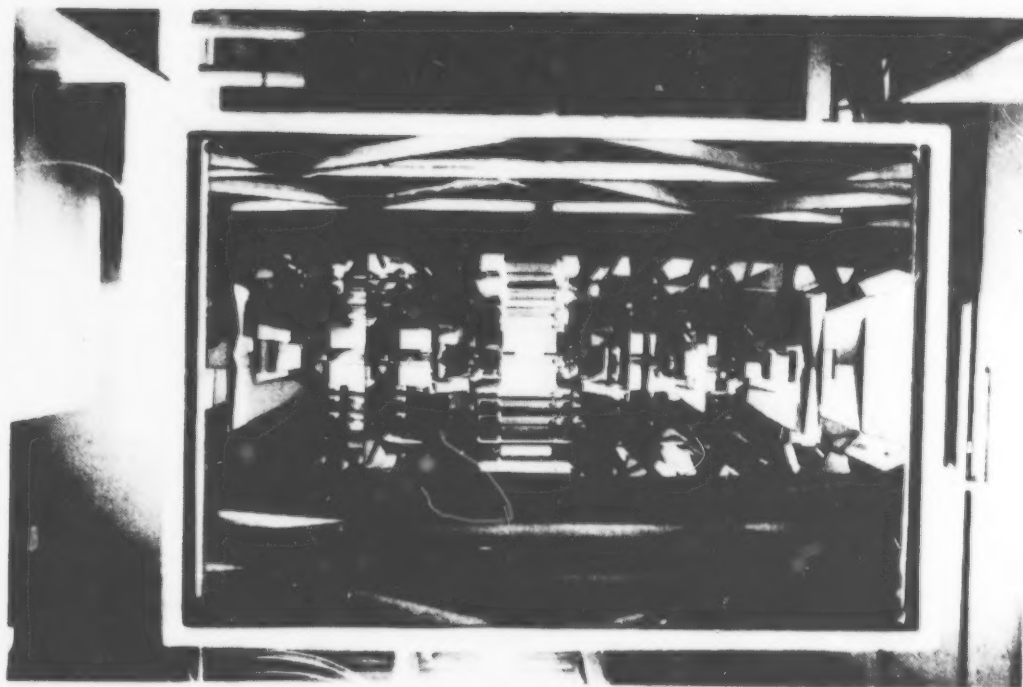
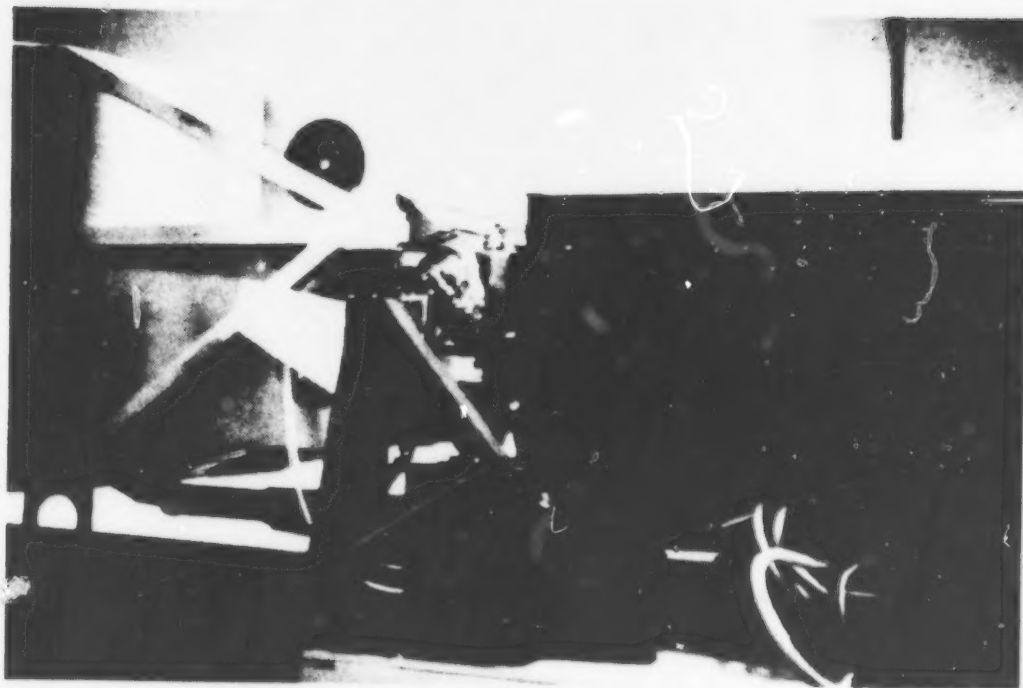


Figure 4.1 Solar Simulator Used at the NSTF

The University of Waterloo is operating two active solar "Centres of Expertise": the WATSUN Simulation Laboratory (WSL) and the Solar Thermal Research Lab (STRL). The WATSUN Simulation Laboratory provides user support and program improvements for the WATSUN computer program, which estimates the performance of active solar heating systems using hourly weather data. The program can be purchased for use on a PC or mainframe computer or accessed over a telephone line (via DATAPAC). The SYPHON and SIMAIR programs (see Section 4.5) can also be accessed on the WATSUN computer. Major research work for 1987-88 at the WSL is to include:

- further examination and improvement of the stratified tank and low-flow collector models
- development of a module for variable-volume storage
- development of a program for photovoltaic systems, including battery backup

Other work will include general program improvement, user support, simulation of standard day testing (in conjunction with Queen's University) and generation of synthetic weather data (in conjunction with the STRL at the University of Waterloo).

In many locations, and especially in developing countries, hour-by-hour solar radiation data are not available. Without this information, computer simulation with programs such as WATSUN is not possible. A computer program has been developed to generate synthetic hourly weather data based on the monthly average clearness index for the location. This program is being made available for the PC version of WATSUN.

The Solar Thermal Research Lab is performing basic research into active solar systems. Major research projects include:

- further improvement to the micro-flow solar DHW system
- development and testing of a low-concentration trough-type collector
- further testing of a honeycomb collector
- development and testing of a natural-convection heat exchanger

- research into a variable-volume storage tank
- development of a simplified model for stratified storage
- characterization of diffuse solar irradiance

The University pioneered the work on micro-flow solar DHW systems (see Section 3.2.1). In this system the collector flow rate is approximately one-fifth that of conventional systems. The lower flow rate allows use of smaller collector tubing and supply/return piping. Current research work on this system is centering on the use of a lightweight collector and a thermosyphoning heat exchanger between the collector and storage tank.

A potential low-cost commercial/industrial collector is also being investigated by the STRL (see Figure 4.1). The collector consists of only three components: a tube-in-fin absorber, tedlar glazing and aluminum container. The collector, referred to as the "Mega-Epsilon" is low-cost because it does not require back insulation, and could be fabricated on site.

The Solar Calorimetry Lab at Queen's University is conducting a research program on test methods and standards for solar collectors and SDHW systems.

The standard two-parameter solar collector model (F_R and F_{RUL}) does not accurately represent the performance of many collector types including evacuated tube and boiling/condensing collectors (see Section 2.1.6). The SCL is continuing to work on the five-parameter collector model and input/output graphs as a better technique for characterizing collector thermal performance. Collector characterization experiments underway include the following:

- day long outdoor testing of a four generic collector types; boiling/condensing, conventional flat plate, Sanyo evacuated tube, and Philips heat pipe, over a range of environmental conditions. The objective is to reproduce the measured collector performance using the characteristic equation and measured weather data.

- indoor testing of a boiling/condensing collector using an environmental chamber that allows testing at low temperatures (below freezing). The objective of this test is to determine the effect of air temperature on collector performance.
- collector testing at NSTF for various flow rates and irradiance levels. The objective is to verify solar design models for low flow applications.

Both CSA and ASHRAE solar collector test standards are currently being revised to incorporate test methods based on SCL research. Current rating techniques for solar domestic hot water (SDHW) systems are based on a short term test conducted under fixed operational conditions. Although this allows for direct comparison of systems operating under these standard conditions it does not allow for comparison at other operational or climatic conditions. Correlation equations have been proposed by SCL that would allow for extrapolation of standard test results, but their validity has not been determined. Component testing is another test method that is being investigated. Experiments underway include the following:

- SDHW system simulation study to determine the sensitivity of standard test results to variations in operational parameters such as load draw profile and volume, mains water supply temperature, daily solar irradiance level and profile, hot water delivery temperature, and ambient air temperature
- Indoor SDHW system testing at NSTF to experimentally validate proposed test procedures and correlation equations.

In addition to the above work, SCL is active in product development for the Canadian solar industry.

The only active solar Centre of Expertise outside of Ontario is the Institut National de la Recherche Scientifique (INRS). Work underway by INRS includes the following:

- laboratory monitoring of commercially available DHW systems
- field monitoring of commercial/industrial demonstrations

- validation study of WATSUN using measured data from commercially available DHW systems

In addition to this work, INRS is very active in product development with the Canadian solar industry.

There are three associations which provide support services for the solar industry: Canadian Solar Industries Association (CSIA), Solar Energy Society of Canada Inc. (SESCI), and Conservation and Renewable Energy Industry Council (CREIC). The CSIA is the active solar manufacturers trade association. This group activities include:

- lobbying/consultation with government on behalf of the industry
- operation of the solar DHW warranty program
- co-ordination of the Solar Energy Products Approval Committee (SEPAC)
- production and distribution of an industry product guide and information brochures

SESCI is a broad-based society made up of academics, researchers, professionals, manufacturers and the general public in all areas of renewable energy. The society, which is part of the International Solar Energy Society, has almost forty corporate members and six hundred individual members. Activities of the society include:

- hosting of an annual technical conference (the 1988 conference will be held in Ottawa)
- publishing of a bi-monthly news magazine, SOL
- lobbying and consultation with government

CREIC is an industry association set up to lobby government for support for the conservation and renewable energy industry. The council has forty corporate members.

4.4 Codes and Standards

Solar heating systems, like all other building systems, must comply with the Ontario and National Building Codes. In addition, there are standards that are applicable only to solar heating systems. The Canadian Standards Association (CSA) has the following standards:

- F378-M1985 Solar Collectors
- F379.1-M1985 Solar Domestic Hot Water Systems
(Liquid-to-Liquid Heat Transfer)
- F379.2-M1985 Seasonal Solar Domestic Hot Water Systems
(Preliminary)
- F383-M Installation Code for Solar Domestic Hot Water Systems
(Draft)

These standards deal with acceptable materials, construction, and design. The standards also define thermal performance, testing, and reporting. The thermal efficiency of collectors is tested according to ASHRAE Standard 93 with some modifications for "non-standard" collectors. The thermal performance of systems is tested according to ASHRAE Standard 95 with some modifications.

The Canadian Solar Industries Association maintains a directory of accepted products. Solar collectors, DHW systems, and manufacturer's quality control are evaluated by the Solar Energy Product Acceptance Committee (SEPAC). Only accepted products are eligible for EMR's solar demonstration program and the CSIA warranty program.

At present, there is no standard for space heating, commercial/industrial, or swimming pool solar heating systems. A standard for swimming pool solar heating systems has not been necessary because of their simplicity and high safety. Solar space heating systems have not been installed in sufficient numbers to justify a standard. Because of the wide range of commercial/industrial system designs, it would be difficult to develop a standard for these systems. Commercial/industrial systems are generally designed by a professional engineer and, if EMR funding is sought, reviewed by EMR engineers.

Most active solar heating systems are covered by adequate standards. An issue that has been recently resolved is the protection of potable water from toxic collector fluids in solar DHW systems. The CSA SDHW standard requires a double-walled copper heat exchanger with a visual means of leak detection or a single-walled stainless steel heat exchanger between the collector fluid and potable water. This requirement must be met, even if stagnant water or propylene glycol is used as the

collector fluid. This requirement has recently been approved by the Plumbing Advisory Council of CSA. Adequate protection for commercial/industrial/institutional systems is still unresolved. Many of these systems use only a single-walled copper heat exchanger if the fluid is no more toxic than propylene glycol, because of the high cost of double-walled and stainless steel heat exchangers. Local plumbing inspectors have been interpreting the Building Code in different ways: in most cases single-walled heat exchangers have been accepted, but some localities require a double-walled heat exchanger with leak detection and a back-flow prevention on the city water supply.

The collector thermal performance characteristics, as given in ASHRAE 93, have been criticized as not being appropriate for some types of collectors (e.g., evacuated tube and thermal diode). Steve Harrison of Queen's University has shown that a five-parameter collector model, as opposed to the standard three-parameter model, can more accurately determine performance [4]. SEPAC, other regulatory bodies and the latest revision of ASHRAE 93 are now using the five-parameter model for non-standard collectors.

A potential safety problem that is not completely covered by standards or plumbing inspections is steam explosions (see Section 3.2.1).

4.5 Performance Prediction Tools

The performance of a solar heating system is a function of the environment in which it operates. As solar radiation and ambient temperature vary throughout the day and the year, so will the performance of the solar heating system. For a designer to know how a system will perform in his location, he must rely on computer simulation, using local weather conditions.

In Canada, the most widely used computer program for solar heating systems is WATSUN. This program, developed at the University of Waterloo, simulates the performance of 13 different solar heating system types: six domestic or service hot water systems, four industrial-process water systems, a batch (or integral collector storage) system, variable volume storage system and a swimming-pool system (Version 10.0). (Earlier versions of the program included solar-assisted heat pump systems and air- or liquid-based space heating systems. Due to lack of use, these modules are no longer included in the program.) Program improvements, user support, and distribution are handled by the WATSUN Simulation Laboratory at the University of Waterloo (see Section 4.2).

There have been only a few studies on the accuracy of the WATSUN computer program. While there are many monitored systems that have had a WATSUN computer run performed, the WATSUN simulation was done with as-designed and not as-built parameters. In these cases, discrepancies between the program and monitored results are more likely to be due to changes in design, or a poor estimate of the magnitude of the load, than inaccuracies in the program. The most complete study on WATSUN accuracy was performed on the National Research Council solar domestic hot water test trailer [13,14]. The long term performance of eleven different SDHW systems were monitored and compared to WATSUN predictions. The study concluded that the WATSUN program can predict performance to within 5%, provided proper input parameters are used. The accuracy of the WATSUN program in predicting performance of commercial/industrial is presented in References 23, 28, 29 and 30. These studies concluded that the WATSUN program is sufficiently accurate for design purposes. The swimming-pool module of WATSUN has been compared to two institutional indoor swimming pools [31]. That study noted that WATSUN appears to under-predict the pool heating load (by approximately 30%). Unlike solar DHW systems, however, the magnitude of the swimming pool load has only a minor effect on the energy delivered by most solar systems.

For Canadian air-based solar heating systems, the most widely used simulation program is SIMAIR. This program, developed by Enermodal Engineering Limited, simulates the performance of solar heating systems for ventilation air preheating, crop drying, and zero-storage space heating. No validation has been done on this program.

There are several other computer programs that are being used by the Canadian solar industry. The SYPHON program, developed by Enermodal Engineering Limited, simulates the performance of water, antifreeze and Freon-based thermosyphon SDHW systems. This program has been compared to monitored data from Institut National de la Recherche Scientifique (INRS) and has been shown to be within 5% of the experimental results [32]. The WATSUN Simulation Laboratory and Enermodal Engineering Limited have recently developed programs for batch solar water heaters. With the WATSUN program, the user must describe the solar water heater construction; the Enermodal program relies on NSTF test results as input.

Outside of Canada, the most widely used computer programs for solar heating systems are f-Chart and TRNSYS. These programs were developed at the University of Wisconsin at Madison. F-Chart estimates performance on a monthly basis using correlating equations. TRNSYS numerically solves the differential equations for heat transfer. The F-Chart program is generally used by designers, whereas TRNSYS, because of its complexity, is used by researchers.

The availability of appropriate weather data, specifically solar radiation is fundamental to any solar simulation program. Atmospheric Environment Service measures hourly values of global solar radiation on a horizontal surface at six sites in Ontario (47 across Canada). For an additional 20 Ontario sites (98 sites across Canada), A.E.S. has derived hourly solar radiation based on other measured meteorological parameters (see Table 4.1). In most cases, the solar designer is not interested in the weather for a particular year, but rather the long-term average. The WATSUN Simulation Laboratory has created a "typical meteorological year" (TMY) for 15 locations in Ontario (27 across Canada). A TMY consists of 12 months from different years, but each representative of the average weather for that month.

As discussed in Section 4.2, Energy, Mines and Resources Canada is funding the WATSUN Simulation Laboratory to provide user services and make program improvements. This funding, along with contracts to the private sector, appear to be meeting the simulation needs of the industry.

Table 4.1: Ontario Sites for Which Solar Radiation Values are AvailableMeasured

Big Trout Lake
Elora
Moosonee
Ottawa *
Toronto (Downtown)
Toronto (Airport) *

Derived

Atikokan *
Earlton
Geraldton
Gore Bay
Kapuskasing *
Kenora *
Kingston
London *
Mount Forest
Muskoka *
North Bay *
Sault Ste. Marie *
Simcoe
Sioux Lookout
Sudbury *
Thunder Bay *
Timmins *
Trenton *
Wiarton *
Windsor *

* Typical Meteorological Year weather data available.

4.6 Design and Installation Manuals

Several design and installation manuals have been published over the last ten years. ASHRAE (American Society of Heating, Refrigeration and Air-Conditioning Engineers) publishes four sources of information on design and installation of solar heating systems:

- 1) ASHRAE H.V.A.C. Systems and Applications Handbook, 1987, Chapter 47.
- 2) Solar Domestic and Service Hot Water Manual, prepared by W.S. Fleming and Associates, 1983.
- 3) Active Solar Thermal Design Manual, prepared by Mueller Associates, 1983.
- 4) Handbook of Experiences in the Design and Installation of Solar Heating and Cooling Systems, prepared by D.S. Word and H.S. Oberoi, Colorado State University, 1980.

The ASHRAE HVAC Systems and Applications Handbook presents an overview of the technology, including component and system descriptions. For detailed design information, ASHRAE refers the reader to the two design manuals. Of these, the Mueller manual is more comprehensive, and provides some practical information on how to avoid design problems. The "Handbook of Experiences" presents more information on general design than on experiences or lessons learned. This handbook was updated in 1983 [31] although not available from ASHRAE. These ASHRAE publications are somewhat dated, and do not deal with many of the techniques used to improve system cost-effectiveness, such as low-flow strategies, mega-collectors and low-cost collector support structures. The publications are for systems installed in the U.S., and as such are not entirely applicable to Ontario.

Canadian design information is available from the CSIA and the federal government. Public Works Canada sponsored the preparation and delivery of a solar design course. The course and accompanying manual [34] covered more the theory of solar heating than of the detailed design, and in that respect is similar to the solar textbook Solar Domestic and Service Hot Water Manual [35]. Public Works Canada also produced a series of technical notes, which cover some of the design and installation problems they encountered, and a guidebook on commissioning and trouble-shooting systems [36].

The installation of solar DHW systems is covered fairly thoroughly by the CSIA publication Manual for the Installation of Residential Solar Hot Water Systems. This publication is an installer's guide, and as such does not cover system design. Because the manual is four years old, it does not discuss installing some of the newer systems (e.g. micro-flow and seasonal systems). CSIA also produces a method (called the shadow chart) for estimating the effect on performance for non-optimum collector orientation or collector shading [37], and a simple design guide for outdoor swimming pool systems, produced for the Ontario Ministry of Energy [38].

In addition to the ASHRAE Handbook of Experiences, there are two other reports that provide useful information on design and installation problems encountered in the field. As discussed in Section 3.2.3, SERI has summarized the results of 20 solar reliability and maintenance studies [18], and Arther D. Little of Canada survey design and installation problems encountered in the U.S. [39]. There have been few published reports that have summarized Canadian field experience. IEA Consulting Group reported on problems that occurred with installation of 20 solar DHW systems in PEI in 1983 [40]. References 23 and 25 summarize the field experience with the Ontario commercial/industrial solar program. A workshop held in Ottawa in 1986 discussed some of the problems encountered in C/I/I solar heating systems [27]. One of the conclusions from that workshop was that over-estimation of water heating loads is one of the most serious design problems. The recently published report entitled Estimating Water Heating Loads for Solar Heating Systems should help address this problem [41].

5. FUTURE TRENDS IN SOLAR THERMAL TECHNOLOGY

5.1 Equipment and Systems

Most research in solar thermal technology is focussing on reducing system costs. To reduce collector costs, three concepts are being studied. As discussed in Section 2.1.2, the absorber plate is the most expensive component in a flat-plate collector, and research is being undertaken to reduce the amount of metal used in the absorber plate and improve the selective coating process. Material content of the fin can be cut in half with little loss in performance by using a tapered fin instead of one with a constant cross-section. Two benefits of the micro-flow system (see Section 3.2.1) are that smaller riser tubes can be used and header pipes can be eliminated by connecting collectors in series. Collector costs may be reduced by using a new type of CPC collector (lowconcentration-ratio stationary collector). An example is the "Mega-epsilon" described in Section 4.3. These collectors use an absorber plate half the size of a flat plate, do not require any back insulation, and are light-weight. These improvements mean that this type of collector may be more adaptable to mass production than flat-plate collectors. Research on this type of collector is being carried out at the University of Waterloo and in the U.S., Israel and Portugal. Work is needed on a simple, low-cost glazing system and in simplifying installation details. The third technique for collector cost reduction is through use of plastics. The U-V stability of plastic glazings has been improving and may soon be suitable for collectors. Techniques for improving collector thermal performance that are being investigated include simplification of evacuated tube collectors and use of convection suppression devices (e.g. honeycombs) in the space between the absorber and glazing.

Major areas of solar DHW system research include:

- refinements to the micro-flow systems (e.g., more efficient pumps and reduced number of connections)
- improvements to thermosyphon/batch systems (e.g., better freeze-protection and lower cost collectors)
- single tank systems, with and without heat exchangers
- self-pumping SDHW systems

One of the major research efforts in the United States is improving the reliability of solar DHW systems. In Canada the Ontario Research Foundation is working on improving freeze protection for seasonal systems. The Solar Energy Research Institute (SERI) has been investigating the use of an all-plastic solar heating system with EPDM solar collectors.

Several new concepts are being investigated for solar Commercial/Industrial systems. With the development of the site-built "mega-collector" (see Section 2.1.2), new low-cost racking systems especially for ground mounting and factory built mega-collectors are being investigated. Racking techniques include integral rack and collector, and inflatable racks. The University of Waterloo is investigating the concept of a variable-volume solar heating system (see Figure 5.1). In this system water passes through the collectors only once and the solar heated water is stored in an open tank. A pump repressurizes this water when hot water is drawn, much like a well water system. The water level in the tank varies according to the solar energy collected and the hot water demand. The advantage of this system is that, by using a low flow strategy, high system efficiency can be achieved. The cost of the system should also be low because an unpressurized tank can be used and no heat exchanger may be necessary.

5.2 Economics

Section 3.1 discussed the costs and performance of solar pool heating systems. This market is a fairly mature market, and is not tied to subsidy programs. While there is some potential for lower costs from larger production volumes, it is unlikely that there will be a major change in the price of swimming pool solar heating systems. The Ontario market activity should remain at current levels, although production could increase significantly as manufacturers market more intensively in the U.S.

Figures 3.10 and 3.11 show E.M.R. projections for the cost of solar DHW systems in 1987 and 1988. These projections show installed system costs dropping to less than \$1800 and a cost performance of \$170/annual GJ. This price is approximately twice that necessary to have

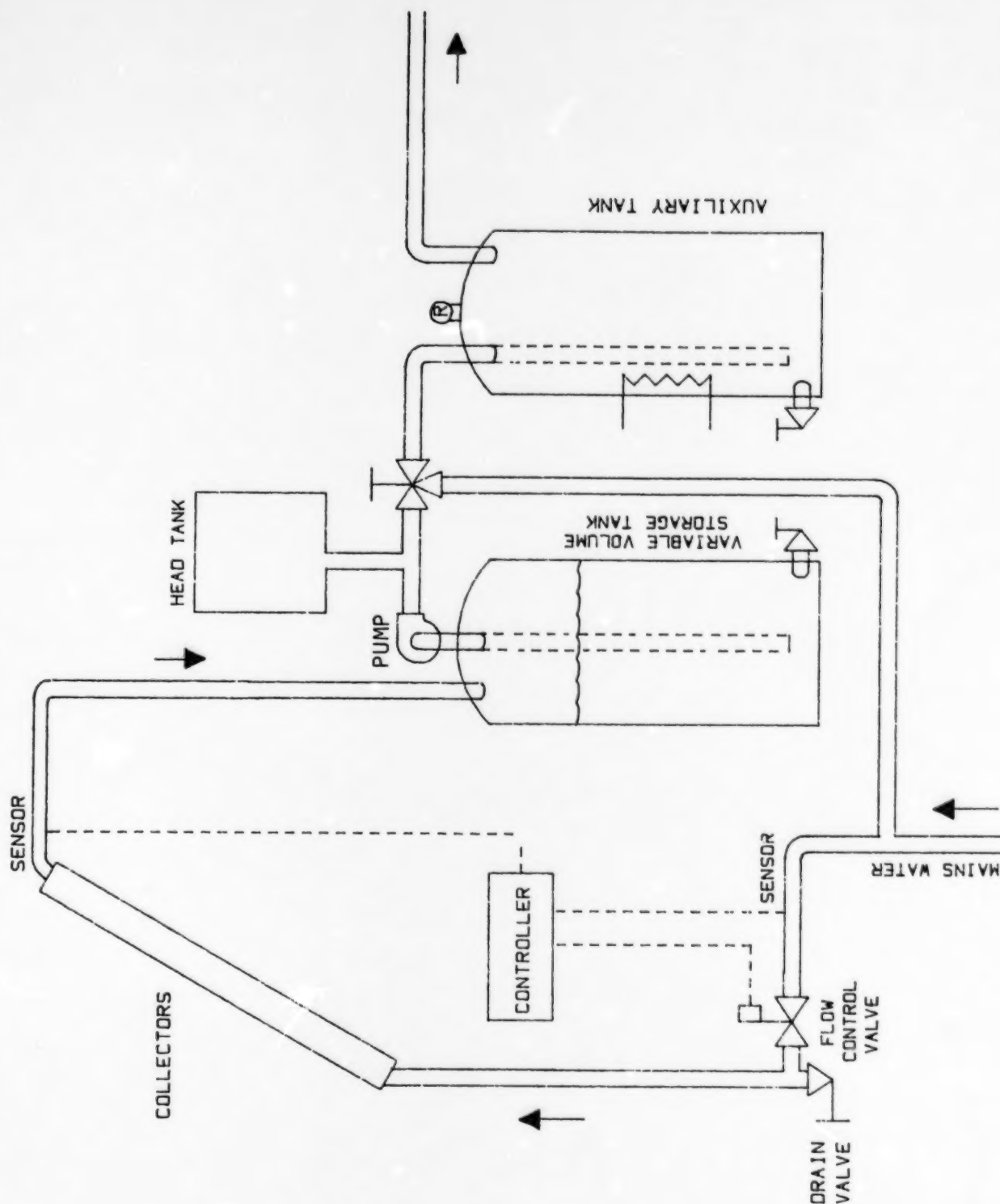


Figure 5.1 Variable-volume Solar Heating System Schematic

market penetration in Ontario at current fuel prices [3]. In those regions of Canada with high fuel prices (e.g., the Maritimes), solar DHW systems may achieve market penetration without government subsidy. The system cost curve is beginning to level out, and it is unlikely that the system costs will drop enough to have market penetration in Ontario without a significant increase in energy costs. It should be pointed out that there are several niche markets where solar DHW systems could be successful. These markets include remote northern communities served by diesel fuel, and cottages that are not connected to the electrical grid. (These cottages would have to use thermosyphon or batch water heaters.)

Figure 3.18 shows the cost performance of Commercial/Industrial solar heating systems. While the difference between predicted and actual performance is decreasing, the cost performance is leveling out at just under \$200/annual GJ. This is about three times the estimated Ontario market threshold cost [3]. As discussed in Section 5.1, there are some new concepts being investigated in the Commercial/Industrial sector. It is unlikely, however, that these improvements will result in systems achieving the market threshold cost in the next few years. In regions of high prices, these reductions may be sufficient to achieve limited market penetration. There are some applications where solar heating may achieve cost effectiveness without any government subsidy. These would include ventilation/process air preheating and fish hatchery water heating.

In any discussion of the economics of solar heating it is important to realize that the price of energy is too a large extent controlled by governments. Oil depletion allowances and debt guarantees to utilities tend to keep the price of conventional energy low. The Ontario Select Committee on Energy estimated that the cost of federal and provincial subsidies to conventional fuels in Ontario for the year 1984 was over 550 million dollars [42]. Energy, Mines and Resources Canada is planning on undertaking a study to determine the true cost of all energy sources. Only when the true cost is known can a definitive statement be made about the economics of solar heating.

6. CONCLUSIONS

The following conclusions can be drawn from this report.

Annual Canadian sales of solar equipment have levelled off at about 99000 square metres and 14 million dollars with 40% of the market being in Ontario.

There are three main markets for solar equipment: seasonal pool heating, residential water heating and commercial/industrial process water and air heating. The market for space heating is virtually non-existent.

The sale of swimming pool collectors is a mature and well-established market. Solar swimming pool systems are reliable and being installed without government subsidy. The success of one Ontario manufacturer has led to approximately 40% of the Canadian production being exported to the U.S.

The cost of solar domestic hot water systems has fallen by 60% since 1981. System reliability has improved dramatically, although controller and pump failures remain a minor problem. System performance is often low, because the system is oversized relative to the load. Solar DHW system cost performance should be reduced by 50% in order for these systems to compete in the Ontario market place without government subsidy.

The current cost performance of solar Commercial/Industrial/Institutional systems is less than one-third of the 1981 value. Most of the systems, however, are still three to four times too expensive to penetrate the Ontario market without subsidies. Exceptions could possibly include ventilation air preheating and heating of fish hatchery water.

The Canadian solar industry is well served by support services in the areas of testing/rating, standards and design tools.

When government subsidy programs end in 1988, the solar industry will face a difficult task in maintaining market share. There are, however, several niche markets and regions of Canada where solar heating may have market penetration.

7. REFERENCES

1. Canadian Solar Industries Association, Industry Activity Report, 1987.
2. Stelios Pneumatics, Energy, Mines and Resources Canada.
3. Rollefson, J.P., Canadian Solar Energy Review - March, 1986, report prepared by the Solar Energy Program of National Research Council, May, 1986.
4. Harrison, S. "The Effects of Irradiance Level on Thermal Performance Testing of Solar Collectors", INTERSOL'85, Proceedings of the International Solar Energy Society Conference Montreal, 1985, pg. 1269-1273.
5. Wuestling, M.D., S.A. Klein and J.A. Duffie, ASME Journal of Solar Energy Engineering, August 1985, "Promising Control Alternatives for Solar Water Heating Systems", No. 107, pg. 215-221.
6. Ford, R.C. and M. Vakili, "The Effect of Variations in Storage Volume on Thermal Performance of Solar Liquid Systems", ENERGEX'82 - SESCO Conference Proceedings, Regina, Saskatchewan, August 1982, pg. 552-556.
7. Enermodal Engineering Limited, A Guide to Rock Bed Storage Units, report prepared for the Solar Energy Program of the National Research Council, 1981.
8. Hollands, K.G.T., D.R. Richmond and D.R. Mandlestam, "Re-engineering Domestic Hot Water Systems for Low Flow", INTERSOL'85, Proceedings of the International Solar Energy Society Conference, Montreal, 1985, pg. 544-548.
9. Enermodal Engineering Limited, Computer Parametric Study of Thermosyphon Solar Domestic Hot Water Systems, National Research Council, Report No. SIM-8, 1983.
10. Bell, J.M. "Availability and Performance of Solar Water Heater Systems - 1979", 1980 SESCO Conference Proceedings, Vancouver, 1980, pg. 269-273.
11. Jones, W.R. and J.M. Bell, "Tests of Solar Water Heating Systems - 1980/1981", 1981 SESCO Conference Proceedings, Montreal, 1981, pg. 136-138.
12. Chen, R., "Laboratory Tests of Six Solar Water Heating Systems", ENERGEX'82 - SESCO Conference Proceedings, Regina, Saskatchewan, August, 1982, pg. 548-551.

13. Shewen, E.C., M.J. Chamberlain and B.E. Sibbitt, "Examination of SDHW System Performance", 1983 SESCO Conference Proceedings, Windsor, Ontario, pg. SHW1.1-SHW1.5.
14. Enermodal Engineering Limited, Analysis of Solar Domestic Hot Water System Performance, report prepared for the Solar Energy Program of the National Research Council, April, 1985.
15. TES Ltd., Technical Monitoring of Solar DHW Systems, Report prepared for Energy, Mines and Resources Canada, March, 1985.
16. Buchan, Lawton and Parent Ltd., Monitoring of Residential Solar DHW Systems, report prepared for Energy, Mines and Resources Canada, February, 1987.
17. G.K. Fleming and Associates Limited, Monthly Solar Monitoring Reports - 1983, report prepared for the Ontario Ministry of Energy, 1984.
18. Jorgensen, G.J., A Summary and Assessment of Historical Reliability and Maintainability Data for Solar Hot Water and Space Conditioning Systems, report prepared by the Solar Energy Research Institute, Golden, Co., May, 1984.
19. Bingham, C.E., "Evaluation and Assessment of Reliability and Maintainability Data of Active Solar Energy Systems", Solar'87, SESCO/ASES 1987 Conference Proceedings, Portland, Oregon, July 1987, pg. 65-68.
20. Hugh Trudeau, Energy, Mines and Resources Canada, personal communication, 1987.
21. Carpenter, S.C. and B. Sibbitt, "Monitored Performance of a Solar Heating System with Annual Heat Storage - The Aylmer Senior Citizens' Apartment", INTERSOL'85 Proceedings of the International Solar Energy Society Conference, Montreal, 1985, pg. 73-77.
22. G.K. Fleming and Associates Limited, Monthly Solar Monitoring Reports - 1984, report prepared for the Ontario Ministry of Energy, 1985.
23. Ontario Ministry of Energy, Final Solar Systems Monitoring Report 1985, Toronto, Ontario, 1986.
24. TES Limited, Monitoring of the Commercial/Industrial Solar Demonstration Program - Year 2 Final Report, report prepared for Energy, Mines and Resources Canada, March, 1987.
25. Markowitz, Thomas, "Operation of Solar Heating Systems in Winter", INTERSOL'85 Proceedings of the International Solar Energy Society Conference, Montreal, 1985, pg. 223-227.

26. Energy, Mines and Resources Limited, Summary of CIPH systems, 1987, unpublished.
27. Enermodal Engineering Limited, Design of Cost-Effective Reliable Solar Heating Systems, report prepared for Energy, Mines and Resources Canada, January, 1987.
28. Sibbitt, B.E. and R.H. Wylie, ENERGEX'82 Conference Proceedings, Regina, Saskatchewan, August, 1982 "Simulated and Measured Performance of a Commercial Solar Water Heating System".
29. Buchan, Lawton and Parent Ltd., Solar Heating Design Verification Study, report prepared for the Ontario Ministry of Energy, 1983.
30. Sharp, Gary, Comparison of Monitored and Simulated Performance of Solar Heating Systems, draft report prepared for Energy Mines and Resources Canada, 1987.
31. Enermodal Engineering Limited, Evaluation of the WATSUN Swimming Pool Module, draft report prepared for Energy, Mines and Resources Canada, May, 1987.
32. Institut National de la Recherche Scientifique, Monitoring of Seasonal SDHW Systems Under Controlled Conditions, report prepared for Solar Energy Program, National Research Council, March, 1985.
33. Ward, D.S., H.S. Oberoi and S.D. Weinstein, How to Solve Materials and Design Problems in Solar Heating and Cooling, Energy Technology Review No. 77, Noyes Data Corporation, Park Ridge, N.J., 1982.
34. Unies Ltd., Solar Design Course Manual, prepared for Public Works Canada, 1982.
35. Duffie, J.A. and W.A. Beckman, Solar Engineering of Thermal Processes, John Wiley and Sons, New York, 1980.
36. Public Works Canada, Guidelines for the Preparation of Start-up, Commissioning and Monitoring Procedures: Engineered Liquid Loop Solar Heating Systems, Jan, 1983.
37. Canadian Solar Industries Association, The Shadow Chart Method and Collector Orientation Penalty Charts for Solar DHW Systems, 1983.
38. Canadian Solar Industries Association, Solar Heating for Swimming Pools, available from the Ontario Government Bookstore, 1982.
39. Arthur D. Little of Canada Limited, Survey of United States Domestic Solar Water Designs and Experiences, report prepared for Solar Energy Program National Research Council, 1982.

40. IEA Consulting Group Ltd., Evaluation of Installation Methods of Solar Domestic Hot Water Systems in the Maritime Provinces, report prepared for Energy Mines and Resources Canada, 1983.
41. Enermodal Engineering Limited, Estimating Water Heating Loads for Solar Heating Systems, draft report prepared for Energy, Mines and Resources Canada, 1987.
42. The Select Committee on Energy, Final Report on Toward a Balanced Electrical System, Second Session, 33rd Parliament, Government of Ontario.